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AN HYPOTHESIS TO ACCOUNT FOR THE MOVEMENT IN THE CRUST OF THE EARTH.[1]

I WISH to propound an hypothesis to explain the vertical movements in the crust of the earth. As preliminary thereto I propose to set forth the most elementary phenomena of dynamic and structural geology in a summary manner so as to exhibit the nature of the facts requiring explanation.

The earth is composed of four bodies surrounded by the ether.

First, there is a central nucleus constituting the principal mass.

Second, there is a crust of structurally disposed rock surrounding the nucleus, the thickness of which is comparatively small.

Third, there is an aqueous body surrounding the rocky crust, through which the islands rise, the largest of which are called continents. On these islands there are many lakes and rivers which ramify into innumerable brooks, creeks and rills.

Fourth, there is an aërial mantle of air extending to a limit which is not well determined.

Fifth, these four bodies, one outside the other, in succession, are surrounded by the ether.

The earth is thus composed of encapsulated globes enclosing a nucleus and bathed in ether, to designate which certain defini-

[1] Read at the November meeting of the National Academy of Science, Boston, 1897.

tive terms are needed. I shall, therefore, speak of the nucleus, the rocky crust or crust, the aqueous envelope or envelope, and the aërial mantle or mantle, and shall call them all spheres. For the sake of clearer distinction, these spheres may be called (1) the centrosphere, (2) the lithosphere, (3) the hydrosphere, and (4) the atmosphere. It must be observed that the ether is common to all of the celestial bodies, and perhaps penetrates them as it does the earth.

The centrosphere is the chief mass and has a density of 5.6. By reason of this great specific gravity, which is about twice that of the rocky crust, it is often supposed to be metallic. Geologic facts in a vast system lead to the induction that the centrosphere does not exist in the solid state; if it is metallic the weight reduces it to a trans-solid condition. To this condition the form of the earth testifies, as it is an oblate spheroid assuming the figure of a fluid under the combined action of gravity and rotation. There are facts which have led physicists to conclude that it must have a rigidity said to be equal to that of steel. This rigidity may be explained as a function of its rotation, revolution, and molecular motion, when the physicist and geologist would be in substantial accord.

The theory of a metallic centrosphere seems adequately to account for the trans-solid state, as the metals are found to flow under pressure; but the molten material which from time to time is brought to the surface from the interior of the earth never reveals this metallic constitution. It may be that there is a zone of matter beneath the structural rock and overlying the metallic nucleus which is penetrated by heat, now here, now there, and only these molten rocks are extravasated; or it may be that the solid state is limited by heat in one direction and by pressure in the other in such manner that all rocks flow under great pressure as do the metals.

The stony crust has been revealed by direct penetration to a depth of more than six thousand feet, but it is indirectly revealed in many regions to a much greater depth, perhaps in extreme cases to fifty or sixty thousand feet.

The islands of dry land have all been beneath the sea at some time or other, and all show that they have been submerged more than once, some more frequently than others. During that portion of the history of the crust, which is the theater of geological investigation, these periods of submarine condition in one region always appear to be contemporaneous with periods of subaëreal conditions in some other region. Thus there seem to have been regions of dry land and regions of ocean bottom coexisting with a large predominance of oceanic area.

The aqueous envelope covers the rocky crust over about three-fourths of its surface, and has an average depth of about twelve thousand feet, though in extreme cases the bottom of the sea is more than five miles below its surface, while in some few cases mountains rise to more than five miles above the level of the sea. It is certain that we are now able to study rocks which were deposited at depths much greater than that of the mean depth of the ocean, and there are many cases where rocks found on the summits of high mountains are known to have been deposited at great depths beneath the sea. Great regions of country are at one time submarine, and at another subaërial. These oscillations of upheaval and subsidence are oft-repeated in geological history, and the swing of oscillation seems to have been in some regions tens or scores of thousands of feet where they reach the maximum, and to be only tens or scores of feet at the minimum, so that the surface of the earth, in so far as it has been studied geologically, is found to give evidence of oscillations of level varying in these quantities.

These variations are geographically heterogeneous, one region may have its oscillation on a small scale, another on a large scale, the minor oscillations forming distinct geographical series and the major oscillations forming distinct geographical series; that is, one region has been subject during geological time only to minor oscillations, and another during the same time to major oscillations.

We must now more fully consider the nature of these movements. Sometimes upheaval is by anticlinal flexure, where the rocks are lifted along a line of upheaval and caused to dip away on either side in gentle or abrupt slopes which are sometimes beautifully curved; but such an upheaval often seems to be accompanied by a subsidence on the flanks. Symmetrical anticlinal flexures are not very common, but often one side slopes gently while the other is abruptly deflected. This abrupt slope is especially subject to rupture, in which case faults are substituted for flexures. Thus a block which dips gently in one direction has its margin, on the side of a fault, displaced as an abrupt escarpment. Blocks formed in this manner often careen upon their edges, so that the strata may become vertically disposed or quite overturned where the lower formed strata are found on top. Between careened blocks and flexed blocks no line of demarcation can be drawn: the same block in different parts of its course may be bent or broken, and the flexed blocks themselves be quite overturned. The rocks which are upheaved or depressed by faulting and flexing, one or both, are always found to be ruptured in line of the faults or flexures, and also transversely to them. This rupture is often minute, so that the sheets of rock are faulted and jointed and thus found in blocks of varying dimensions, but all very minute as compared with the widely spread formations from which they are broken. Thus the whole system of rocks, of igneous and aqueous origin alike, are broken into blocks by faults and ruptures, and still further divided by planes of deposition, so that the structural crust is a system of fragments sometimes with an area of many yards, other times an area of fractions of inches. When we compare these blocks with the great area of the structural crust we find that it is but an accumulation of blocks that are to the formations what grains of sand are to the blocks. We must now realize that the structural crust nowhere has a continuous coherence; that faults, joints, and partings render it a vast body of minute and loosely accumulated fragments. All of this upheaval and subsidence with flexures, faults, joints, and partings seem to

have been brought into this condition by intermittent convulsions often exhibited in earthquakes.

Having contemplated the lithosphere as a body moving in upheaval and subsidence, and shown what is about the maximum and minimum of these oscillations and their paroxysmal character, we are prepared to consider the structure of this crust.

In all geological ages volcanic eruptions have occurred and rocky material from the depths has been brought to the surface. Such appearances of lava at the surface have been very common in human history, and they appear to have been just as common in all the geological ages revealed by science. Lavas vary in chemical and mineralogical constitution, but this variation is within narrow limits. All of the mineral substances known to mankind appear, but are intimately mixed as minute ingredients. Lavas, therefore, are intimate mixtures of many substances, the average of which falls within narrow limits. It would appear from our present knowledge that the primordial surface of the earth was cooled lava and that lava has been erupted from time to time through all of the great geological ages.

Upon these cooled surfaces a new crust of rocks from below and rocks from above appears to have been spread. Wind waves and tidal waves are forever beating the lands and undermining the cliffs and distributing the materials beneath the sea. Then atmospheric agencies disintegrate the rocks and the rains wash the sands into the streams which carry them into the lakes and into the sea. By many cognate processes the lands are worn down and the sea bottoms built up; the amount of detritus thus accumulated in zones about the meandering shores is great, so that in regions of maximum activity formations are accumulated thousands of feet in thickness.

The winds contribute to the material which falls into the sea; plant life also furnishes its quota; accumulations of vegetation are ultimately consolidated among the formations as beds of coal; and animal life adds to the marine formations, for corals, shells, and bones are all brought to be buried in the sand, and often extensive formations of calcareous matter are

thus produced. From these sources the sedimentary rocks are brought to be mingled with the eruptive rocks and intercalated among them, while in turn they are thrust between the sedimentary rocks.

Layers of rock of sedimentary origin appearing as strata are commingled with other masses of rock of volcanic origin which come from the interior. Sometimes the lava flows under or between the sedimentary strata. When great masses of lava are found in these conditions they are called lacolites. Thinner sheets are called intrusive rock. Beds poured over the surface are called coulées. The floods of lava come through fissures and fill them both below and above coulées, intrusions, and lacolites. Such fissure formations are called dikes; where the lava comes forth in volcanoes, the orifices are filled with molten rock which consolidates and are then called chimneys; great bodies of lava are ejected by some volcanoes as scoria and ashes, and often the ashes are minutely comminuted; the expulsion of such material is doubtless due to the production of gases and vapors, especially of steam, and the comminution is probably due to the explosive actions of particles of water expanded into steam. Great volcanic cones are often formed by the piles of scoria and ashes which are extravasated, and the ashes themselves when highly comminuted are drifted by the wind, sometimes far away from the locus of eruption. Beds of ashes and scoria formed in this manner are called tuff. So the bodies of rock formed by eruption are commingled with the bodies formed by sedimentation, and all are known as formations. Both the sedimentaries and the eruptives undergo a further change, which to a greater or less extent obscures their origin, for the original formations are metamorphosed, that is, recrystallized and lithified; so that the planes of sedimentation are partly or largely obscured and the beds of lacolites, intrusive sheets, coulées, dikes, chimneys, and tuffs have a new structure imposed upon them, and are then known as metamorphic rocks.

An attempt has been made to define formations; now they must be considered in a new light.

The land areas have always been subject to degradation by rains, rivers, and waves, and the materials washed from the land have been carried into the sea and there deposited; thus the continuance of dry land area is comparatively ephemeral. Not only are the lands degraded in this manner, but when they reach the level of the sea they continue to subside; when above the sea they are speedily unloaded, but when brought to the level of the sea or nearly so the islands, though having their loads discharged, continue to sink. The regions which have received the detritus of the islands and are thus loaded by them, are elevated into the island or continental condition; thus land areas rise to be unloaded and then sink, while oceanic areas are loaded and then rise to become land areas. The extent of this upheaval and subsidence and the vertical movements, involved together with the vast transportation of material from land to sea, seems to be enormous when we contemplate the almost silent and unseen agencies by which it is accomplished.

In considering large areas of the surface of the earth, as, for example, the great continents or zones of archipelagoes, we reach certain generalizations of prime significance.

Regions of great denudation are also regions of great deposition, regions of great eruption, regions of great upheaval and subsidence, and also regions of great flexure and fracture; thus denudation and deposition, eruption, displacement, as subsidence and upheaval and as fracture and flexure, are correlated in this manner: that where there is more of one there is more of all; where there is less of one there is less of all.

Geologists have found no law, condition, or cause by which to explain these phenomena of the earth's crust as the law of gravity explains the constitution of celestial systems. The search for this law has been almost exclusively in one direction, under the hypothesis of a cooling and contracting earth, but with the lapse of time it has been found inadequate. Attempts have been made to compute the amount of contraction supposed to result from the wrinkling of the crust of the earth in anticlines and synclines. It seems to entirely fail quantitatively.

Contraction does not seem to be an explanation of all or even the chief phenomena which we have briefly set forth. When this hypothesis was considered, flexion seemed to be the chief method of displacement; now we know that fracturing and faulting is the chief method in regions of maximum action. When inclined rocks are studied they seem to have been stretched, as evidenced in the elongation of particles transverse to the strike, and they seem further to have been stretched by the opening of fissures and joints. Altogether it may be affirmed that displacement does not teach the doctrine of a contracting earth, or, if that statement is too strong, it does not give evidence of a sufficient contraction necessary to the hypothesis, and it also fails to explain the concomitant phenomena.

With this hypothesis another is associated, namely, that the centrosphere of the earth is metallic, for which no vestige of inductive evidence has yet appeared; and the stupendous fact remains that the centrosphere has more than twice the density of the crust. All eruptive rocks which come into the purview of science are found to have an average constitution which is about the same as that of the sedimentary rocks. It is found by experiment in the industrial arts that under pressure metallic and other substances flow; and geology teaches that all of the other rocks are secularly deformed under differential pressures, so that rocks highly metamorphosed in this manner are twisted, contorted, and kneaded into new shapes. Finally, there is now abundant geologic evidence to show that the faulting near the surface appears as flexure at greater depths, and finally that flexure appears as molecular readjustment at still greater depths, expressed in slaty structure where the particles of the rocks are rearranged in parallel planes.

The metals of the normal condition have great density, but in a pure condition are found only in exceedingly minute quantities; all the other rocks have a small density. If now we assume that all rocks flow under pressure, that the critical point is variable and that the modulus of compression is also variable, being greater for the lighter rocks and less for the heavier, and that

this modulus is greatly accelerated at the critical point, we have a law which will regiment the facts of geonomy as the facts of astronomy are marshaled by the law of gravity.

Under this theoretic law of the accelerated modulus of compression at the critical point for different substances, subsidence and upheaval are explained. The reassumption of constitutional structure in crystallization and glassy lithification necessitates expansion, and thus upheaval is explained. When lands rise and are denuded, the process of relithification in the centrosphere continues upheaval and exposes the lands to further upheaval, and this process goes on until an equilibrium is reached at the epoch when the land is brought to the level of the sea by degradation. On the other hand, as land is loaded the subjacent crust rocks are brought within the zone of accelerated compression, and this process continues while the loading continues until it is brought to a close at the epoch when the land area from which the detritus is taken is brought to the level of the sea and transportation ended so that loading ceases.

Universal contraction by cooling must still be postulated as an agency for the destruction of equilibrium, or perhaps we may find this agency in astronomical conditions; but some such agency is necessary for the continuation of the process. But the changing of material from the interior to the surface and the changing of load from one district to another by transportation under the law of the accelerated modulus of compression is the principal agency of upheaval and subsidence.

This doctrine was proposed several years ago by myself, but has received little attention except among a few geologists engaged in this branch of research; from its reception by these gentlemen I am encouraged to repropound it.

J. W. Powell.

ESTIMATES AND CAUSES OF CRUSTAL SHORTENING.[1]

INTRODUCTORY.

IN THE following paper I shall use the words crust and nucleus as terms by which to conveniently refer to the outer known solid shell of the earth, of which we have direct knowledge, and to the core surrounded by the crust, of which we have only inferred knowledge. The use of these terms in this sense is independent of any hypothesis as to a sharp boundary between the two, and of any theory as to the condition of the interior of the earth. So far as my present purposes are concerned, the nucleus may be entirely liquid, entirely solid, part liquid and part solid, or in a state of matter of which we have no knowledge.

The intricate phenomena of earth deformation, and particularly that form of deformation called folding, has led geologists to assume, in order to account for the facts in the field, that the surface of the earth must have been vastly shortened during geological time. Some instances of the estimates of the amount of crustal shortening may be mentioned.

Dutton[2] thinks, to explain the phenomena of folding since the close of the Cretaceous, that the radius of the earth must have been shortened more than thirty miles. He states that the plications are so great that we must assume a contraction on some circles of latitude since the commencement of the Permian amounting to many hundreds of miles, and this amount of contraction is small, he says, compared with that involved in the Laurentian rocks. Heim[3] estimates the transverse shortening of

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] A criticism upon the contractional hypothesis, by C. E. DUTTON: Am. Journ. Sci., Vol. VIII, 1874, p. 121.

[3] Mechanismus der Gebirgsbildung, von ALBERT HEIM: Basel, Band II, 1878, S. 213.

the Alps to be seventy-four miles. Le Conte[1] estimates the transverse shortening of the Coast Ranges of California to be from nine to twelve miles. Claypole[2] estimates the transverse shortening of the Appalachians in Pennsylvania to be forty-six miles. McConnell[3] thinks the folding of the Laramie range of British America required a transverse shortening of twenty-five miles.

In the above estimates of shortening by Heim, Claypole, Le Conte, and McConnell, I have inserted the word *transverse*, to call attention to the fact that shortening in only one direction has been considered by these authors. It is clear that to obtain an adequate idea of the effect of crustal corrugations, it is necessary to know in square miles the surficial lessening of the crust of the earth as a result of deformation. However, it appears that if in other mountain ranges the shortening is proportional to the estimates above given, the total amount of surficial decrease must be enormous. This would be true even if the deformation of ancient mountain ranges, the stumps of which are buried under later rocks, were ignored. Moreover, it is possible that the amount of folding and consequent shortening of the Paleozoic and older rocks, buried under the Mesozoic and Cenozoic strata, may be as great or even greater than the amount of shortening involved in the deformation observable at the surface.

The theory of mountain-making as a result of secular cooling has been repeatedly attacked along the lines of the vast contraction demanded by the supposed facts of the field, and the small contraction resulting from secular cooling, the only cause ordinarily assigned for contraction. Dutton[4] calculates that the

[1] On the structure and origin of mountains, with special reference to recent objections to the contractional theory, by JOSEPH LE CONTE: Am. Journ. Sci., Vol. XVI, 1878, p. 98.

[2] Pennsylvania before and after the elevation of the Appalachian mountains, by E. W. CLAYPOLE: Brit. Assoc. Rept., Montreal meeting, 1884, p. 718.

[3] Geological features of a portion of the Rocky mountains, by R. G. MCCONNELL: Geol. Surv. of Can., Ann. Rept., Vol. II, Pt. D, 1886, p. 31.

[4] Loc. cit., p. 120.

contraction due to secular cooling is mainly confined to the outer 200 or 300 miles of the earth, and states: "Although no estimate can be made of the contraction of this portion, it is probably safe to say that its volume cannot have been diminished so much as one-tenth; and if we were to assign thirty miles as the diminution of the earth's radius since the formation of a cooled exterior, we should probably reach the utmost limits consistent with Fourier's theorem."

It is believed, upon the one hand, that there may have been great overestimates of the amount of crustal shortening, and upon the other hand, that important causes for nucleal contraction may exist which have not been sufficiently considered. It is the purpose of this paper (1) to examine the evidence upon which estimates of crustal shortening have been made, and to consider the methods to be followed in making estimates of shortening, and (2) to summarize the known causes which may exist for nucleal contraction and crustal corrugation. The paper may thus be divided into two parts. In Part I, I shall consider the shortening of the outer surface of the earth accompanying folding, faulting, jointing, cleavage, fissility, and vulcanism and cementation; and in Part II, I shall consider the causes which may account for the shortening represented by the phenomena.

PART I. ESTIMATES OF CRUSTAL SHORTENING.

Folding.—The deformation of folding undoubtedly involves shortening, but it is believed that it does not necessarily require nearly so much shortening as has been believed. Estimates of shortening resulting from folding have not considered the effects of the following phenomena: (1) the thinning of the layers produced by folding; (2) the composite character of folds and the rapid variations in the closeness of the folds of the various orders; and (3) the effect of gliding on the limbs of folds.

1. In order to make an estimate of the amount of shortening involved in folding, it is necessary to recall the nature of the deformation of the individual beds and formations. It has been

shown[1] in another place that the mashing, flowage, and the shearing motion involved in differential movement between the layers necessarily involves thinning of the limbs of the folds or thickening of the troughs and crests, or both. Even where the

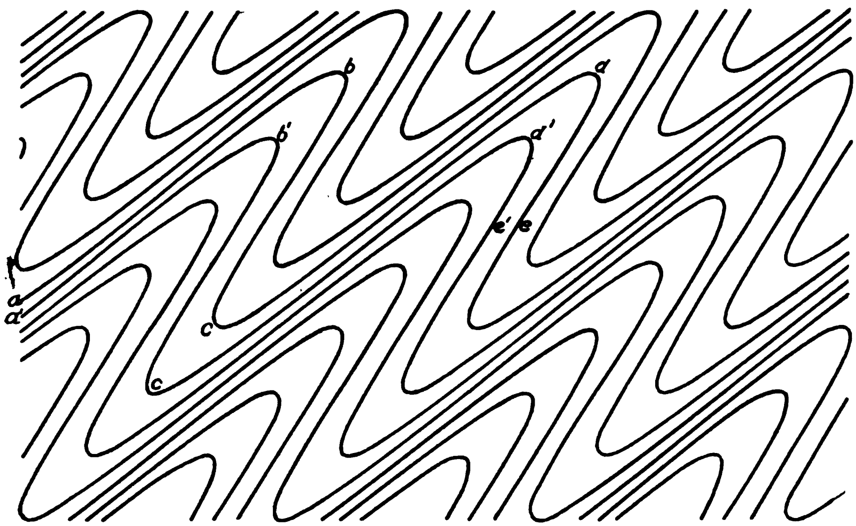


FIG. 1.— Similar monoclinal folds.

folds are not close, in case the folds are similar,[2] the limbs may not be much more than half as thick as are the troughs and crests (Fig. 4). This distortion becomes more and more important as the folding becomes closer, and in isoclinal and monoclinal folds, in which the strata turn back upon themselves, the amount of thinning of the limbs or thickening of the troughs and crests is very great (Fig. 1). A layer when traced out in such a set of folds alternately thins and thickens, and the section if developed on a plane, would alternately greatly widen and narrow (Fig. 2). The length of the developed layer should be the length of its central part. The excess of material for each

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, p. 599.

[2] Loc. cit., pp. 599–600.

curve on the convex side of such a central line would equal the deficiency on the concave side, and consequently such a developed layer truly represents its mass and average length. If it be assumed that the original horizontal stratum had a

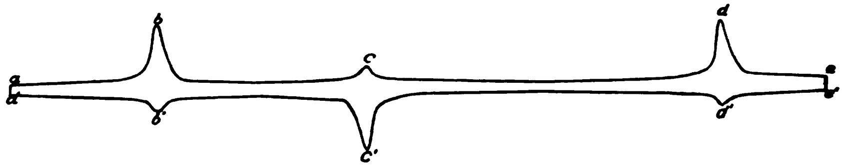


FIG. 2.— Development of a part of a layer of Fig. 1.

thickness equal to the thicker parts of the folded stratum, it would follow that the developed stratum is much longer than it was originally. However, probably in no case is this assumption wholly correct, and in many cases it is far from the truth. The weaker and stronger layers require consideration separately.

At most places the evidence seems to show that during deformation the anticlines and synclines of the weaker layers have been thickened. However, since during the deformation there is shearing motion under pressure all along the limbs, it can hardly be doubted that in many cases the thinning of the layers is a more important phenomenon so far as their length is concerned, than thickening on the anticlines and synclines.

In the stronger layers, often no evidence of thickening is anywhere seen. Upon the contrary in many cases, as will be shown below, the layers are actually elongated by tensile fracture upon their convex sides and therefore cannot have been thickened. Radial open fractures upon anticlines and synclines, due to tension, are beautifully exhibited in the southern Appalachians (Fig. 8). The openings in many cases have been filled with quartz. These joints are evidences of tensile forces. Where stretching of anticlines and synclines occurs in the zone of flowage, this is undoubtedly due to the great friction between the layers, and to their positions on the convex sides of the neutral planes. The limbs of the stronger layers, like those of the

weaker beds, are subjected to differential shearing under pressure, and if distortion occurs they must be thereby thinned.

The actual thinning and elongation of layers as a result of folding has been noted by Le Conte[1] as an important phenomenon in the Coast Ranges of California, and by Reade[2] in various mountain ranges.

According to Gilbert,[3] during the introduction of igneous rocks, which formed the Henry mountains, the pressure of the magma normal to the strata was so great that they were extended laterally by flowage a sufficient amount to cover the domes. In the case of the Holme's arch the linear extension was about 2 per cent.

The amount of thickening or thinning, which any given formation or layer undergoes, will of course depend upon many factors, among which attitude, strength, pressure, amount of differential movement or shearing are to be considered.

As noted by Reade,[4] the attitude of the layers is of the greatest importance. In their initial position the tendency of the pressure is to thicken them. This tendency continues as the layers are tilted, until the average dip is 45°. As soon as the layers upon the average have a greater inclination than 45° (Fig. 1), the average effect of the tangential pressure is unquestionably to thin the layers, although some members at certain places, and especially at the turns, may be thickened. When it is remembered that in the closely-folded mountains the layers generally have dips greater than 45°, and as explained later (pp. 16–17) such layers usually turn quickly at the anticlines and synclines, it becomes evident that the thinning of the layers and their consequent elongation, as a result of tangential pres-

[1] On the structure and origin of mountains, with special reference to recent objections to the contractional theory, by JOSEPH LE CONTE: Am. Journ. Sci., Vol. XVI, 1878, pp. 299, 301, 302.

[2] The origin of mountain ranges, by T. MELLARD READE: London, 1886, pp. 176, 208, 211.

[3] Geology of the Henry mountains, by G. K. GILBERT: Rept. U. S. Geog. and Geol. Surv. of the Rocky mountain region, 1877, pp. 80–82.

[4] Loc. cit., pp. 216–217.

sure in positions which average greater than 45°, may be very important. In reference to the other factors, the greater the pressure, the greater the tendency for thickening and shortening at angles less than 45°, and the greater the tendency for thinning

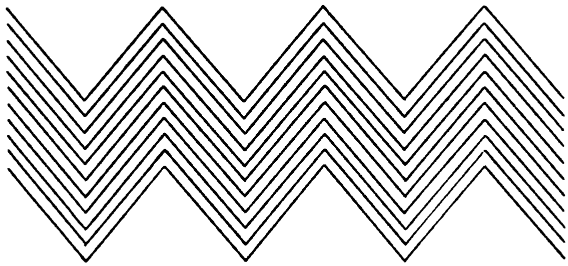


FIG. 3.—Similar upright folds with angular crests and troughs.

and lengthening at angles greater than 45°. The greater the shearing between the layers, the greater the thinning. The greater the rigidity of any given layer, the less the thinning.

The foregoing statements are understood to apply to strata which are so deeply buried that the deformation of the layers results from true interior distortion of them. In the upper zone of fracture these statements need to be modified, as subsequently explained.

With present data only these qualitative statements can be made. But, it seems probable that in the earlier stages of the development of folds, the average thrust thickens instead of thins the layers. However, where the folds are very close, and especially in isoclinal and overturned folds, it can hardly be doubted that upon the average there is considerable thinning and consequent important elongation of the layers. For folds of a given average closeness the average amount of distortion is not so great where the strata bend back upon themselves with sudden turns, as where the bends occur gradually (compare Figs. 3 and 4), although the distortion at the angles may be greater than at the corresponding places upon the gentle turns. In nature the deformation is ordinarily between the two extremes figured.

The fact that the distortion is less in folds with sudden turns than in those with rounded turns, is believed to be a cause why this deformation so frequently occurs in closely-folded rocks. The angular deformation requires less work, and there-

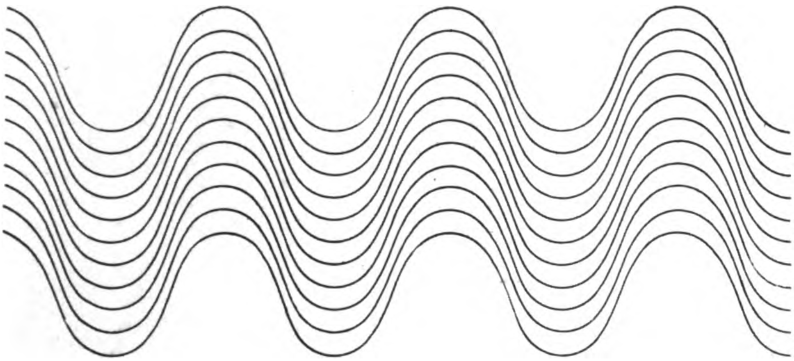


FIG. 4.—Similar upright folds with rounded crests and troughs.

fore less energy than the other form. As the stresses slowly accumulate until the elastic limits of the rocks are surpassed, the deformation which will occur in any given case in order to relieve the stresses is that which requires the least expenditure of energy under the existing conditions. This is the old principle that a mass under stress gives way along the lines of least resistance.

2. In estimating the amount of superficial shortening involved in folding, it is necessary to consider what and where strata shall be selected for estimation. I have shown that if there is no thinning or thickening of the layers (Fig. 5) folds rapidly die out above and below any given folded layer. I have also shown that similar folds are only possible by profound distortion of the layers (Figs. 1 and 4), unless the turns are very abrupt. Agreeing with theory, actual geological sections are a compromise between parallel folds and similar folds, the folds rapidly varying in closeness in different parts of a mountain mass, vertically and laterally.[1]

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, pp. 599–601.

In this connection it should be remembered, if the theory of a level of no lateral stress be true, that a good reason exists for the lessening folding and distortion of layers with increasing depth.

Whether or not this theory as ordinarily stated approximates

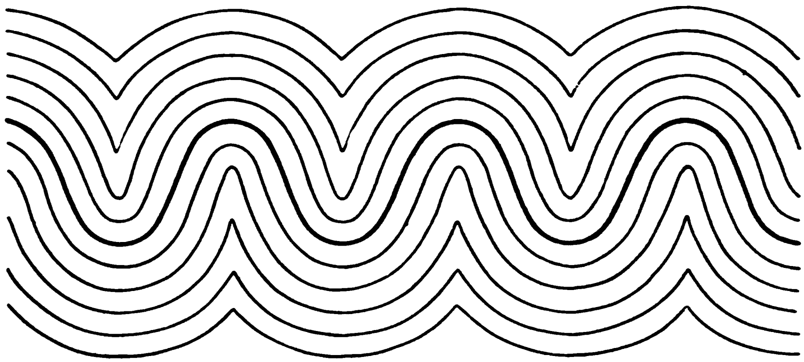


FIG. 5.— Parallel upright folds with rounded crests and troughs.

quantitative correctness, it is certain that the amount of shortening must somewhere decrease with increase of depth; for infinitesimally near the center of the earth the amount of shortening must be infinitesimally small. Since with present knowledge we can only conjecture the law under which folds die out in depth, though we are certain that they must die out, one is not justified in assuming that folds similar to those at the surface continue even for moderate depths.

If this principle be ignored in estimating shortening, a serious error may be made. The formation being followed may plunge beneath softer formations which show close plications. If it be assumed that similar plications also effect the formation below to be measured, this may lead to a considerable overestimate of the amount of crustal shortening (Fig. 6).

Also the lateral variation in closeness of folding may lead to error. If the layer or formation to be measured is not continuously exposed, it may be visible where it chances to be most closely folded and be concealed where more openly folded. If at

the places of less folding the strata chance to be hidden, the plications of other strata must be selected to fill in the gap. Layers may be selected which exhibit close folding. But even if layers are selected which show the least folding of any in sight,

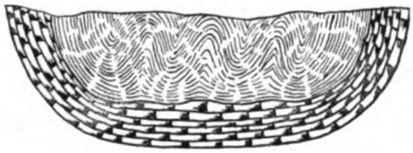


FIG. 6.—Simple fold below composite folds.

there is still a possibility that a considerable overestimate may be made of the closeness of folding and of the amount of crustal shortening.

For oftentimes, where a formation upon which estimates of shortening are being made, disappears below the surface, this results from its plunging downward as a part of a synclinorium. It is believed that upon the average synclinoria are less closely folded than anticlinoria. Anticlinoria are places of crustal thickening resultant upon close plications, whereas synclinoria are areas ot depression as compared with the anticlinoria, but not really areas of depression as compared with the unfolded districts. If the plications of synclinoria were as composite as anticlinoria, this would involve an equivalent amount of thickening of the crust, and consequently equal elevation with the anticlinoria unless a large amount of material, to compensate for the difference in elevation, had flowed from below the synclinornia to below the anticlinoria. Doubtless the flowage of the kind suggested does take place to some extent, but to no such extent as would be involved in this hypothesis

Willis's experiments most beautifully illustrate the composite character of the folding of anticlinoria as compared with the intervening synclinoria.[1] The above reasoning applies exactly

[1] The mechanics of Appalachian structure, by BAILEY WILLIS: 13th Ann. Rept., U. S. Geol. Survey, Pt. II, 1893, Pls. LXXVII, LXXXI, LXXXII, LXXXIV, LXXXV, LXXXVI.

to his experiments. When the strata were compressed in these experiments there was flowage from below the synclinoria, but not a sufficient amount to allow the synclinoria to become as plicated as the anticlinoria, and at the same time to be at a lower level.

3. In anticlinal mountain masses the cores, composed of the oldest and originally deepest-buried strata, are often less closely plicated than the strata on the flanks of the mountains, which are composed of younger rocks. In estimating the crustal shortening of such mountain masses, we have, therefore, the

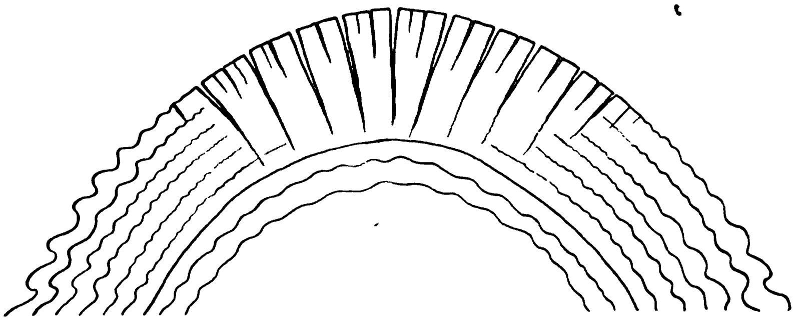


FIG. 7.— Possible relation of secondary folds to joints.

difficulty already mentioned, that is, folds of different layers vary in their closeness. This occurs notwithstanding the fact that upon the limbs one would expect that differential movement between the layers, or shearing, which tends to stretch them rather than to produce plications, are at a maximum. The greater folding of the limbs, as compared with the cores may be partly explained by the principle already given, that in general folds die out as depth increases, and consequently the older strata are least folded. However, the plications are probably to be chiefly explained by the gliding of the material down the slope upon the flanks of the mountain, because under the stress of gravity (Fig. 7). The strata on the crests may have been removed by erosion, or, as exolained in another place (see p. 24), the stresses may have there produced joints. In either

case the material on the flanks is no longer held in position by the tensile strength of the rocks on the crest, and under the stress of gravity slides down the slope, and this results in corrugations. The plications upon the flanks may thus be partly or fully compensated by separation of the material along the crests. However, the plications may be inferred, in estimating crustal shortening, to have extended to the part removed by erosion. In this case the amount of crustal shortening due to folding would be overestimated. In reality, the original length of the strata was that of a gentle continuous curve of the order of magnitude of the mountain mass.

The question may be asked as to the reality of the existence of the gliding effect above assumed as a result of the action of gravity. In another place[1] I have fully discussed the forms of the secondary folds which occur in composite anticlinoria and synclinoria of the first order. It there appears that the secondary folds upon the flanks of the mountains so commonly have attitudes which must have resulted from this gliding effect, that the composite folds, the secondary folds of which show such attitudes, have been called normal composite folds. This discussion cannot be here repeated, but if the argument given be correct, the gliding effect due to gravity producing secondary corrugations upon mountain flanks is a significant phenomenon, and consequently the cause here assigned for overestimates of the amount of crustal shortening is of importance.

It is clear that in appealing to the force of gravity to pro duce corrugations upon the slopes of the mountains, I am follow ing Dana[2] and Reyer.[3] However, I do not follow the latter fully. He makes the gliding the cause of the formation of mountains, whereas, it is clearly an effect, following the mountain-making. Material cannot glide down until it has been raised up. My

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, pp. 608–615.

[2] Geological results of the earth's contraction in consequence of cooling, by JAMES D. DANA: Am. Journ. Sci., Vol. III, 1847, p. 185.

[3] Theoretische Geologie, by E. REYER: Stuttgart, 1888, p. 829.

present point is that if the corrugated parts are alone considered, and the jointed part or the part removed by erosion ignored, that the average crustal shortening may be greatly overestimated.

If the considerations presented in the foregoing pages have weight, it is clear that the actual measurements in the field of the amount of crustal shortening involved in folding presents great difficulties, and the question naturally arises as to the best practicable methods of procedure.

1. So far as practicable, the same formation should be measured throughout a section, and if it is necessary to transfer from one formation to another, the greatest care should be exercised in order to avoid the errors which may result from changing from a formation to another lower or higher, and also to avoid the error which may come in as a result of the lateral change in closeness of plication.

2. The strongest formations available should be selected for measurement.

This selection should be made because the stronger formations have less composite curves than the weak ones. As a consequence they are less distorted during the folding than the weak formations. These facts may be observed in almost any good section of closely-folded heterogeneous strata. The more composite crenulation, but not the greater thinning and thickening, of the weaker layers may be illustrated by bending a rectangular pile composed of bunches of paper alternating with cardboards, the pile being held firmly either mechanically or with the fingers at the edges, so that slipping between the laminæ may be hindered at the places held. In this experiment, at the crest or trough, spaces form between the stronger layers, and in these spaces the weaker layers take on secondary crenulations. In natural geological sections the pressure upon the limbs is frequently sufficiently great so that the material of the weaker layers flows toward the openings on the anticlines or synclines, and partly or wholly occupies them. In many places some of the weaker layers are quite pinched out upon the limbs.

The physical cause for the simple folding of strong layers

and the composite folding of the weaker layers is that already assigned for another kind of deformation on p. 17, namely, under given conditions, the deformation occurs which demands the least expenditure of energy. To deform the strong layers in a composite way requires a large amount of energy. To deform the weak layers in a composite way requires much less energy. The simple deformation of the strong layers and the composite deformation of the weak layers demands less energy than would be required to deform all the layers in a similar manner, so that the deformation would average the same as in the case of the unequal deformation of the strong and weak layers.

Under different circumstances the strong layers vary greatly in the simplicity of their deformation. In case the load is not too great, as explained by Willis, the strong layers are bent into large, simple folds. If, upon the other hand, the load is too great for the strata to support, the strong layers are folded in a composite manner. Both of these cases fall under the principle that the deformation occurs which requires a minimum expenditure of energy, for in the case of the lighter load, it requires less energy to elevate the load on the anticline, or to somewhat depress it on the syncline, than it does to greatly distort the strong formations. But in the case of the great load it requires less expenditure of energy to distort the strong layer a sufficient amount to make it develop composite folds than it does to elevate the load. But as above stated, even in the case of composite folding of the stronger layers, the weaker layers adjacent to them show still more composite deformation.

The statement made that the strong formations should be selected for tracing above the surface and for measurement is therefore justified.

3. From the places where the strong formations plunge below the surface to the places where they reappear, only the most gentle curves should be assumed (Fig. 6).

4. From the places where the formation which is being measured is lost because removed by erosion, only the most

gentle practicable curves should be assumed to the places where the formation reappears, and even if this be done, as shown (pp. 20–22) an overestimate may be made of the length of the formation.

5. It should be ascertained whether the formation measured has upon the average been thinned or thickened, and a corresponding allowance should be made.

If the principles are not appreciated upon which the foregoing precautions are based, with the natural, indeed almost inevitable tendency for one to pick out strata for measurement which have suffered severest deformation here, and severest deformation there, we may be sure that estimates of shortening will have comparative little value.

Jointing.—In another place[1] I have explained that joints may be of two kinds, tension joints and compression joints. Tension joints in simple folds may form in one direction at right angles to the bedding, or nearly so, in the zone of fracture (Fig. 8). In the case of complex folding, two sets of tensile joints intersecting each other at right angles may develop, both, however, still normal to the bedding or nearly so. Compression joints, forming in shearing planes, are ordinarily more or less diagonal to bedding. However, the greatest compressive stresses may approximate angles of 45° to the bedding, in which case the shearing fractures would be nearly normal to bedding. Compression joints, like tension joints, may develop in two directions at right angles to each other.

In the gentle folds of the Paleozoic of the Mississippi valley and the strata of the plateau country of the far West, joints are normal to the bedding, or nearly so, corresponding in position to the direction of the folding. For instance, southern Wisconsin is a gentle southward-plunging anticline, in other words, the principal fold has a nearly north-south axis, and the rocks dip east to Lake Michigan and west to the Mississippi river. Corresponding to this arrangement are numerous joints in a north-south direc-

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 668–672.

tion. However, the plunge of this anticline varies in passing from north to south. In other words, there is here a great but very gentle cross fold, and corresponding to this is another set of joints which run in an east-west direction.

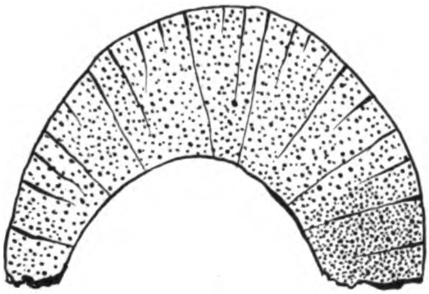


FIG. 8.—Tensile joints.

The same arrangement of joints is still better illustrated in the closely folded Allegheny mountains, and the Coast Ranges of Oregon and California. In the Allegheny mountains, as may be seen by sections along the railroads (for instance, the Pennsylvania, and Baltimore and Ohio) in the stronger beds there are two sets of joints everywhere corresponding to the strike and dip, in other words, corresponding to the two directions of fracture due to longitudinal and transverse folding.

Such joints may be seen both in anticlines and synclines. They occur in sandstone, grit, or limestone. Where the layers are a foot or more in thickness, and the rocks are gently folded, the joints may be several feet apart. Where the layers are closely folded the joints are frequently less than a foot apart. In the thinner layers, those from two to six inches in thickness, the joints are ordinarily less than a foot apart, and where closely folded are but two or three inches apart. Indeed, in some cases of close folding, the two sets of joints are so close together as to break the formations into a set of parallelopiped blocks, the dimension along the bedding being the least of the three, that is, the joints are closer together than the thickness of the beds.

It is apparent that the Paleozoic strata of the Mississippi valley and of the Plateau region, the Alleghenies, and Coast Ranges were folded under such conditions that the curves of the folds were produced not by actual bending of the layers, but

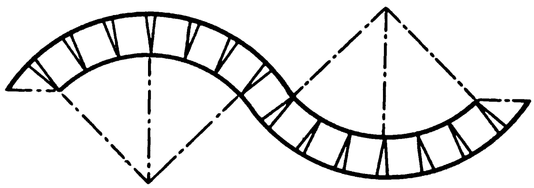


FIG. 9.— Diagram of radial openings produced by tensile fracture.

by numerous fractures, with a slight displacement of each block, resulting in a curved form (Figs. 9 and 10).

Now these joints must have been produced by tensile stresses or by shearing stresses. If they are of the first class, it is self-evident that the production of the joints involved surficial elongation (Fig. 9). If they are of the second class, their production may have involved all of the surficial elongation (Fig. 10), and it will be explained in a subsequent number of this JOURNAL[1] that joints of this kind are believed to be widespread. Some reasons for this belief may here be mentioned. These joints in many regions show a marked tendency to a vertical attitude, as in figure 10. Also the kind of displacements generalized in figure 10 has been observed at various places. Moreover, such joints are closer together the closer the folding, and in some cases they are so close as to make the intervening masses approach leaflets, as, for instance, in sandstones and shales on the Chesapeake and Ohio canal, three miles west of Hancock, Md.

In both the cases of joints produced by tension and shearing above described, there is no real elongation of the strata, but merely a displacement of the blocks causing surficial elongation. In the case of the tension joints this elongation is due to the fact that spaces are measured; in the case of the

[1] Deformation of rocks, by C. R. VAN HISE: JOURN. GEOL., Vol. VI, 1898.

shearing joints the apparent elongation is due to the fact that the measurements are diagonally across the blocks, instead of following the bedding.

From figure 9 it is plain that the average theoretical elongating effect of tension joints is directly as the thickness of the layers or formations through which the joints continuously extend, and indirectly as the radius of curvature. In the field it oftens happens that as a result of the position of a layer or formation upon the convex side of the neutral plane of deformation, the different blocks are separated from one another on the concave sides of the curves as well as on the convex sides.

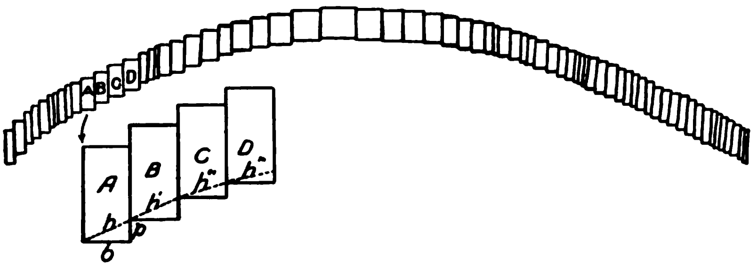


FIG. 10.—Surficial elongation resulting from shearing joints.

From figure 10 it is plain that the surficial elongating effect of the shearing joints is great in proportion to the displacements along the joints, and to their frequency. The apparent length in any case is the sum of the hypotenuses of the right angle triangles ($h + h' + h'' + h'''$, etc., Fig. 10), the bases of which are the lengths of the blocks parallel to the bedding, and the perpendiculars of which are the displacements.

It is not to be concluded from these illustrations that there is no crustal shortening as a result of joint folding. Shortening might occur even if the entire bending were accomplished by tensile joint fracturing. Also in the case of the shearing joint fracturing the rubbing of the blocks against one another might produce shortening.

However, if an estimate of the original surface of the layers were made, upon the supposition that it was as great as it would appear to be if developed on a plane, this would result in a

considerable overestimate of the amount of its original surface.

In many of the weaker layers of folded rocks is a diagonal jointing, due to differential motion, and cutting this diagonal jointing nearly at right angles is a diagonal fissility.[1] The whole may result in thinning the limbs of the folds, just as does the shearing motion in the case of folding by plastic flow.

It is very desirable that the quantitative value of the lengthening effect of jointing should be known for various kinds of deformation. This, however, is an exceedingly difficult task. The quantitative value of the surficial elongation due to jointing for any deformation of an area can be only approximately determined after an extensive and close field study of the district. Consequently, for the present, I am obliged to be content with comparative statements which rest upon my own judgment, and which may be questioned by other observers. I believe the elongating effect of jointing to be quantitatively of sufficient importance that it should be taken into account in estimates of crustal shortening. I believe the lengthening effects of joints are important in connection with the estimates of shortening due to folding where the folds on the flanks of mountains may be due to a downward gliding effect, and be compensated by the joints (see Fig. 7), as explained on pages 20–22. However, I suppose that the elongating effect of jointing is not so great as that of the distortion of closely folded rocks in the zone of flow, as explained on page 16.

Faults.— Faults are ordinarily classified into normal faults and reverse faults. The normal faults involve an elongation of the crust of the earth as certainly as the reverse faults involve a shortening of the crust of the earth.[3] The very names, normal and reverse faults, show that the first are of far greater abundance,—are in fact the rule.

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 651–654.

[2] Supplementary notes on deformation of rocks, by C. R. VAN HISE: JOURN. GEOL., Vol. V, 1897, pp. 190–191.

[3] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, p. 674.

However, since the hade of a reverse fault is usually flatter than that of a normal fault, the shortening due to a given vertical displacement of a reverse fault exceeds the shortening due to the same displacement of a normal fault. In considering the elongation or shortening of the crust of the earth by faults, this factor must be considered, as well as the factor of their relative frequency and area of distribution. However, reverse faults are usually confined to closely-folded areas, while normal faults frequently occur in these same areas, developing in the final stages of deformation, and are also present throughout great regions where reverse faults are absent, as, for instance, in the Great Basin and Plateau regions. It is therefore wholly possible that the amount of shortening of the crust of the earth resulting from reverse faults is more than compensated by elongation of normal faults, and thus the sum total of deformation by faulting result in dilatation rather than shortening of the crust of the earth.

Cleavage.—Cleavage has been supposed necessarily to indicate an important shortening of the crust of the earth.

It is, however, to be remarked that the shortening of cleavage must not be considered if the amount of shortening involved in the folding is counted for the same region; for cleavage is a phenomenon which may result from distortion under conditions of flowage, and the shortening represented by folding includes that involved in the simultaneous production of cleavage.

Moreover, cleavage is possible without any shortening whatever. I have shown in a previous paper[1] that cleavage may be produced by simple shearing motion parallel to the surface of the earth. The inclination of the cleavage will depend upon the amount of the shearing. Shearing of a very moderate amount will produce cleavage with dip as low as 30°. In the production of cleavage by shearing, each individual particle is shortened. Where shearing motion parallel to the surface of the earth results in cleavage inclined at 30°, the amount of shortening of each particle is about .4. However, the direction of shorten-

[1]Deformation of rocks, by C. R. VAN HISE: JOURN. GEOL., Vol. IV, 1896 pp. 636–637, 868–872.

ing is inclined to the surface of the earth. The shortening involves an equivalent elongation in another direction. This elongation is at right angles to the direction of shortening, and is inclined to the surface of the earth in a direction opposite to

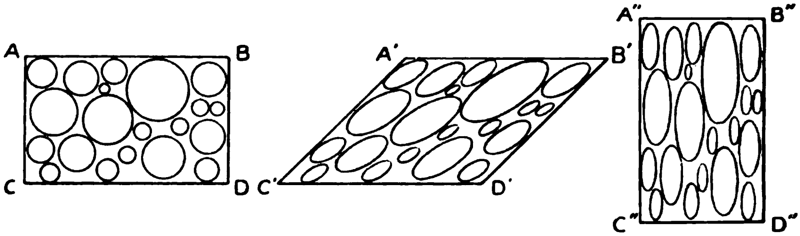


FIG. 11.—Inclined cleavage produced by shearing motion parallel to bedding without crustal shortening, and vertical cleavage produced with crustal shortening.

the direction of shortening. The forces producing a shear involve two couples, which at any given moment produce a tension in the direction of elongation and a compression in the direction of shortening. Thus, as a result of the work of the two couples in the production of cleavage by shearing parallel to the bedding, the direction of tension and the direction of shortening being inclined to the surface of the earth in opposite directions, are in such relations to each other at any given time and place that the total effect is neither elongation nor shortening of the crust of the earth.

This is illustrated by figure 11. The rectangle *ABCD* is deformed into the parallelogram *A'B'C'D'*, by shearing motion parallel to the bedding. The cleavage is parallel to the flattened ellipsoids. The area of the rectangle and parallelogram are the same, and also the line *A'B'* at the surface of the cleaved rock is of the same length as the line *AB* of the original rock before it was deformed and cleavage produced. The Ocoee slates of the Hiwassee river, west of McFarland for several miles, show a cleavage dipping to the southeast at an angle averaging about 30°. The beds are easily recognizable, and are very nearly horizontal. They show no bendings which can be dignified by the name of folds. However, even in this case the

shearing motion parallel to the surface may have been accompanied by nonrotational distortion, as a result of horizontal thrust. The deformation resulting from such stresses is shown by figure 11. In this case the rectangle *ABCD* is deformed into the rectangle *A'B'C'D'*. The shortening is here great, and yet the beds are horizontal, although thickened. In nature the two cases may be combined in any proportion. In the Hiwassee slates already mentioned close observation shows slight crenulations of the generally horizontal strata. These suggest that the shearing motion parallel to the surface has been accompanied by horizontal shortening, and that both kinds of deformation are here combined. But the relative value of each is entirely unknown, and it is therefore impossible to give any estimate of the amount of crustal shortening involved in the deformation which resulted in the cleavage described.

We therefore conclude that while monoclinal cleavage over considerable areas may involve no crustal shortening, it is probable, in most cases of such cleavage, that there is a real crustal shortening, although it is impossible to estimate its amount.

After an inclined cleavage has been produced in any region, the conditions of deformation may change as a result of denudation, and fractures may form parallel to the cleavage. These fractures may be wide apart or close together. After these partings are produced, displacements may occur similar to those of joints (Fig. 10) or they may be closed by the falling down of the overhanging material, precisely the same as in the case of ordinary normal faults. The possible elongation resulting from these secondary movements may partly or fully compensate for the earlier movements resulting in shortening.

Fissility.— Fissility is a name applied to an actual close parting of a rock which results in the production of laminæ. Fissility may possibly develop as an independent structure, although it is believed that it is commonly a structure secondary to cleavage. It is further thought that fissility generally forms as the result of ruptures along shearing planes parallel to the cleavage, from compressive rather than tensile stresses. Where

these ruptures occur close together, and there is slight differential movement, a distributive displacement may be produced, which is equivalent to a reverse fault, and which therefore results in crustal shortening, or the distributive displacements may be similar to those of the shearing joints of figure 10 and therefore result in crustal elongation. However, as in the case of cleavage just described, a region which is under compressive tangential stresses, and therefore is deformed by distributive faulting parallel to fissility, may later be under conditions of tensile tangential stresses. In this case partings will occur between the fissile laminæ, and elongation result. These elongations are strictly analogous to the elongation of normal faulting. The openings may be closed, as in the case of normal faulting, by a dropping down of the overhanging strata, or by methods of injection or cementation, as explained below.

Minute normal fault slips, secondary to cleavage or fissility, have been observed in the crystalline rocks near Blowing Rock, N. C. While during the formation of cleavage or fissility it is probable that shortening took place, it cannot be asserted that the subsequent elongation did not compensate for this, and it cannot be ascertained whether the total effect of the various deformations in this district resulted in elongation or shortening.

Vulcanism and cementation.— After a secondary structure has been produced, whether it be cleavage, fissility, joint, fault, or irregular structure, it may be taken advantage of by igneous intrusions in connection with deformation. These injections with the assistance of orogenic movements may greatly widen the openings so as to make places for great dikes. Such injections result in the local elongation of the crust of the earth. The injections may be divided into two classes, regular, approximately parallel injections, which take advantage of the above regular structures, and irregular injections.

Throughout considerable districts the amount of parallel injected materials is equal to, or surpasses the amount of original materials in which the regular secondary structures were

produced, and thus there are large extensions of the areas affected.

This is finely illustrated by many districts of the Piedmont plateau crystalline and semicrystalline rocks. A convenient district in which to see the phenomena is that of New York. In the Manhattan gneiss in the vicinity of New Rochelle, the injected material in many places surpasses in quantity the amount of the original gneiss. Parallel injection is also finely illustrated by many of the districts of pre-Cambrian gneisses in eastern Canada, and western North America. In the latter region one of the most beautiful illustrations is that of the Madison Canyon gneiss in Montana. In these regions the intrusions seem to have occurred when the rocks were rather deep-seated, and doubtless in this zone intrusions are of much greater importance than nearer the surface. However, within a few thousand feet from the surface, extensive intrusions may take advantage of joints, faults, or radiating fractures. This is illustrated by the numerous granite dikes along joints in the Sierra Nevada granite; by the dikes of Crazy Mountain, Montana;[1] by the trap dikes of the Triassic of the Connecticut valley; by the dikes of Cape Ann, Massachusetts, where, according to Shaler,[2] the dikes occupy from 5 to 10 per cent. of the surface of the country; by the dikes of western Scotland;[3] and by the dikes of many other areas.

Besides the parallel and radiating intrusions just considered, great irregular intrusions of material have occurred on a vast scale. Irregular intrusions are especially numerous among the older rocks. The injected material may occupy a large part of the surfaces of the districts affected. The irregular injections of igneous material find lateral space largely by mashing or corrugating adjacent rocks, and this causes vertical expansion of the crust. Irregular intrusives may be found in the same districts in

[1] Livingston folio, by JOSEPH P. IDDINGS and WALTER H. WEED: Geol. Atlas of the United States, No. 1, 1894.

[2] The geology of Cape Ann, Massachusetts, by N. S. SHALER: 9th Ann. Rept. U. S. Geol. Survey, 1889, pp. 579–602.

[3] Geological map of Scotland, by SIR ARCHIBALD GEIKIE.

which the parallel injections are also found. Scores of illustrations of irregular intrusions, so extensive as to occupy important or even major parts of various districts, could be mentioned of any of the great groups of rocks. A number of instances are given on pages 49–50.

All openings which may be taken advantage of by injection may also be taken advantage of by underground water deposits, and thus by a combination of fracturing and cementation the area of the rocks is increased. That the rocks may thus receive an important extension of their surface area has been noted by Shaler.[1] While parallel and irregular cementation by water solution may not be so important as igneous injection in the lateral extension of rocks, it is a more widespread phenomenon, and undoubtedly has an important effect. Wherever openings have been produced in relatively deep-seated rocks (that is, in the lower part of the zone of fracture, and in the zone of combined fracture and flowage[2]) it appears to be the rule that cementation follows them, and thus rock material again occupies the entire space.

In regions where fissility has been developed, the laminæ are cemented by layers of infiltrated material, which in many places average as wide as the laminæ cemented. This is seen at many localities in the southern Appalachians. Cementation is not more important in closing the spaces between laminæ than it is in closing joints, faults, and irregular fractures. Such cementation may be found in the same districts as the depositions along the planes of fissility, and thus double the effect, or it may occur in districts in which fissility is unimportant. The Marquette district of Michigan finely illustrates the latter. Entire formations have been broken by innumerable joints, irregular cracks, or even brecciated. The openings are now entirely closed by cementation.[3] Since the time of this cementa-

[1] The crinetic hypothesis and mountain building, by N. S. SHALER: Science, Vol. XI, 1888, pp. 280–281.

[2] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, pp. 589–594, 601–603.

[3] The Marquette iron-bearing series of Michigan, by C. R. VAN HISE and W. S.

tion, when the rocks had neared the surface by denudation, other fractures formed which have not been cemented.

Thus throughout regions in which injection or cementation is extensive, there is complete evidence of important local extension of the crust of the earth. Moreover, in the case of the igneous material, it is certain that it acts as a wedge forcing the material apart. It also is possible that the wedging effect of cementation may not be unimportant. While it is probable that upon the average the deformations which produce the fractures taken advantage of by the entering material resulted in shortening the crust of the earth, it is by no means certain that in many cases at least the extension of cementation or injection did not largely compensate for the shortening due to the deformation.

Shortening of Algonkian and Archean rocks.— No one yet has been bold enough to attempt a quantitative estimate of the shortening represented by the older mountains, the stumps of which only remain. But oftentimes it has been stated in a general way that probably the pre-Cambrian folding, and consequent shortening, is as great or greater than all subsequent folding.[1] While I am not able to disprove this conjecture, it seems to me that the closeness of corrugation assumed as general for the ancient rock is not justified by the facts. I shall separately consider the Algonkian and Archean rocks because they are so dissimilar.

In many regions the Algonkian sediments are not closely plicated. For instance, in the Lake Superior region, including the Original Huronian district, the Keweenawan and Upper Huronian sediments are very gently folded. The same statement applies to other extensive areas of pre-Cambrian sediments in Canada. The sedimentary rocks of the Adirondacks are more severely folded, but still the folding is not close. The crystal-

BAYLEY: Mon. U. S. Geol. Survey, No. XXVIII, 1896, Pls. VII, VIII, IX, XXIII, and XXVI.

[1]A criticism on the contractional hypothesis, by C. E. DUTTON: Am. Journ. Sci., Vol. VIII, 1874, p. 121. Origin of mountain ranges, by T. MELLARD READE: London, 1886, pp. 133–153.

line and semicrystalline rocks of the Blue Ridge in some places are closely folded and have secondary structures, but are in many places not closely corrugated. For instance, the quartz-schists of Tullulah mountains are in very gentle folds. The folding of the pre-Cambrian sediments in western America is also rather simple. The thick Grand Canyon series is but gently undulating. The Uinta sandstone is in a great simple arch. The thick pre-Cambrian series of Montana is gently folded. The pre-Cambrian of the Wasatch and Medicine Bow mountains are somewhat more closely corrugated, but not nearly so closely as many areas of Paleozoics in the New England region. However, there are some districts in which the folding is close and complex. This is the case with the Lower Huronian of the Vermilion and Menominee districts, and to less extent of the Marquette district, all in the Lake Superior region. The folding of the Original Laurentian district is of the most complex kind. However, even in these districts of close folding, it cannot be stated that the shortening is greater than is the case in the closely folded Tertiary rocks of the Alps.

Thus it appears that somewhat gentle folding is the rule with the pre-Paleozoic sedimentary rocks, as with the Paleozoic and post-Paleozoic, but in occasional districts the deformation, as in the later rocks, is of the most intense character. Therefore, during early geological periods, as during later geological time, orogenic movements have been concentrated along definite zones. Apparently since the beginning of Algonkian time large parts of the continents have escaped violent orogenic movements.

From the foregoing I do not mean to assert that the pre-Paleozoic sedimentary rocks are upon the average not more closely folded than later rocks. Indeed, the reverse must be the case, for the earlier rocks have partaken in subsequent foldings. The point upon which I insist is that there is no such great difference in the amount of deformation as has been thought by many.

However, it is in the Archean rocks that the apparent plications are most severe, but it is to be remembered that we have here no

criterion upon which to make an accurate judgment, as bedding is missing. As seen (p. 29), cleavage is no criterion upon which to make estimates of shortening, and this is especially true of monoclinal cleavage, and such monoclinal cleavage is found in the Archean for great distances in various places, as for instance, in the Blue Ridge and Piedmont plateau, in southwest Montana, and in various areas in Canada. Also banding is no criterion, for, as has been seen in this paper, and shown in another place,[1] the regular banding in the Archean rocks is in many cases probably due to cementation and injection. However, it is often found in these ancient rocks that the secondary structures themselves, such as slatiness and schistosity, are folded into undulations, but these are in most cases rather gentle. For instance, the schistose structure of the Blue Ridge at Doe River is a single anticline, and on the Nacoochee-Hiwassee section are two anticlines separated by a syncline. The descriptions of Emmons and King show the same simplicity of structure for the Front Range of Colorado. The undulations of the schists are so gentle that they took them to be the remains of sediments, and gave an estimate of their thickness.

Finally, wherever we find exceedingly irregular and intricate structures in which no estimate can be made of the corrugations, even of the secondary structures, we are sure to find intrusive material intricately interposed, which may itself largely or wholly compensate for the shortening which we see.

I therefore conclude with the present state of knowledge, that we are wholly unable to make any quantitative estimate of the amount of crustal shortening involved in the deformation of the Archean rocks.

Longitudinal shortening of mountain systems.—In all past estimates which have been made of shortening in mountain-making only the transverse shortening has been considered, but in order to obtain a true estimate of the effects of deformation, it is necessary to consider the amount of longitudinal shortening. If it

[1] Principles of North American pre-Cambrian geology, by C. R. VAN HISE: 16th Ann. Rept., U. S. Geol. Survey, Pt. I, 1896, pp. 662–668, 684–688.

be agreed that complex deformation is the rule instead of the exception, as I have maintained in another place,[1] it is evident that longitudinal shortening is an important factor in deformation. As a consequence of cross folds, of reverse faults, and of other cross structures, it may be that the shortening of the crust of the earth in a longitudinal direction during the mountain-making processes is as great or greater than the transverse shortening.

This becomes evident as soon as the ratios between the length and breadth of the mountain chains are considered. The Appalachian system, in its broadest sense, extends from Alabama to the St. Lawrence River, a distance of about 1300 miles. Its breadth is about 75 to 100 miles. The ratio between the length and breadth is about 15 : 1. The Cordilleran system of North America in its broadest sense extends from western Alaska to southern Mexico, a distance of about 4800 miles. The breadth varies from 100 miles at the ends of the system to 1000 miles at the middle. But where this greater breadth occurs there are considerable distances between the different chains so that the folded area is probably not more than from one-half to one-fourth of the total amount. The average width of the folded part is probably somewhere between 300 and 500 miles. Thus the ratio between the length and breadth in this case would be between 16 : 1 and 10 : 1. The Andean system extends the entire length of South America, 4500 miles. This system is a comparatively narrow one, its average width being about 200 miles. The ratio of length to breadth in this case is therefore about 22 : 1.

It thus appears in the cases of these great mountain systems, if the longitudinal shortening involves from one-tenth to one-twentieth as much shortening as the transverse deformation per mile of linear distance, that the shortening of the crust of the earth as a result of the existence of the mountain systems is as great longitudinally as transversely.

In the case of some mountain systems which have considerable breadth as compared with their length, as for instance

[1] Loc. cit., p. 626.

the Pyrenees and the Himalayas, it appears that the longitudinal shortening is relatively more important than in the mountain systems in which the ratios between length and breadth are greater, as in the cases above mentioned. In the case of the Pyrenees this is beautifully brought out by the memoirs of Roussell, which show that cross folds are here important.[1]

In the introduction of the neglected element of longitudinal shortening into the problem of crustal shortening, in mountain-making, we have a factor which, contrary to those above considered, increases the total amount of crustal shortening. In order to properly estimate the effect of the formation of a mountain system upon the area of the surface of the earth, we must know its length and breadth now, as compared with the original length and breadth of the rocks making the mountains. The amount of crustal shortening is then known in surface area, the only proper unit in which comparison can be made, for shortening along one line is of little importance unless it extends over some finite distance transverse to that line. However, the introduction of this element of longitudinal shortening very greatly complicates the quantitative estimation of the amount of shortening of the earth, and such an estimation, in a direction transverse to the mountains, as has been shown, is a sufficiently difficult task if all the factors are taken into account which should be considered.

Although aside from the purpose of this paper, it may be remarked in passing that one of the difficulties which have appeared to confront geologists is not real. Geologists, assuming that all shortening is in a direction tranverse to the length of mountain systems, have been puzzled by the resultant conclusion that the shortening of the crust of the earth is so largely concentrated in a direction transverse to the meridians.[2] When

[1] Étudé stratigraphique des Pyrenees, by JOSEPH ROUSSELL: Bull. Carte Geol de la France, Tome VI, 1893–4, and especially accompanying Pls. I to V.

Étudé stratigraphique des massifs Mantagneux du Canigou et de L'Albere, by JOSEPH ROUSSELL: Bull. Carte Geol. de la France, Tome VIII, 1896–7.

[2] A criticism upon the contractional hypothesis, by C. E. DUTTON: Am. Journ. Sci., Vol. VIII, 1874, pp. 122–123.

one recognizes that longitudinal shortening may be as important as transverse shortening, this difficulty disappears.

Finally, to know the real effect of the deformation in mountain folding it is desirable to know not only the average closeness of the plications in two directions, but the depth to which this average closeness has been observed. In short, in order to obtain the most significant estimates of the effects of crustal shortening, not one dimension of a folded mountain mass, but three, length, breadth, and depth or thickness, should be taken in account. So far as I know, two of these factors, length and depth, have been wholly ignored in all estimates of shortening. The reason for this doubtless is that the difficulties in the way of the consideration of all these factors are insuperable, at least at present.

Shortening of removed formations.—Another element of uncertainty in giving estimates of crustal shortening is the unknown shortening of the rocks which have been removed by denudation. If, as has been supposed, circumferential shortening is at a maximum at the surface of the earth, the strata which have been most deformed have been removed from time to time. It would therefore follow, if we could estimate the amount of total shortening to which the rocks of the crust have been subjected, that this amount would fall short of the real shortening which the surface of the earth had undergone. The erosive forces as they cut off the mountain tops and distribute the material upon the border of the sea, smooth out the earth's wrinkles of age.

Conclusion.—If the argument of the foregoing pages holds, it is clear that we must begin at the beginning in making estimates of the amount of crustal shortening involved in mountain-making. The published estimates have ignored so many factors which must be considered before an estimate can have any quantitative value, that I am forced to the position that they are little more than guesses. It is therefore concluded that the amount of shortening of the crust of the earth, due to its deformation, is an entirely unknown quantity. By this I do not mean to imply that the crustal shortening has not been

very great, but that as yet we can only make qualitative statements in reference to its amount; that quantitative statements are objectionable because they imply a definiteness of knowledge not warranted by the facts, and therefore stay the progress of investigation.

PART II. CAUSES OF CRUSTAL SHORTENING.

Secular cooling.— The first cause of contraction to be considered, and the only one ordinarily considered, is secular cooling. The amount of such contraction has been variously estimated. But the largest calculated amounts which the physicists will allow have always been disappointingly small to the geologists.

Mallet, on the hypothesis that the earth was liquid and had a mean temperature of 4000° F., has concluded that the earth "between its period of liquidity and its present state has shrunk in diameter by 189 miles at the least."[1] At that time, according to Mallet, the earth would have a mean radius of 4053.3 instead of 3958.8 miles. The surfaces of these spheres would be respectively about 206,457,000 and 196,942,000 square miles, and thus the surficial contraction of the earth would be about 9,515,000 square miles.

Dutton, making his calculation on another basis, concludes if the earth once had a nearly uniform temperature of 7000° F., that "if we were to assign thirty miles as the diminution of the earth's mean radius since the first formation of a cooled exterior, we should probably reach the utmost limit consistent with Fourier's theorem."[2] Taking the average radius of the earth as 3958.8 as before, the radius of the earth before contraction, according to Dutton, could not be more than 3988.8. The surface of this expanded earth would be about 199,938,000 square miles, which gives a surficial contraction of about 2,996,000 square miles.

[1] Volcanic energy: an attempt to develop its true origin and cosmical relations, by ROBERT MALLET: Trans. Roy. Soc., Vol. CLXIII, 1873, p. 205.

[2] A criticism upon the contractional hypothesis, by C. E. DUTTON: Am. Jour. Sci,. Vol. VIII, 1874, p. 121.

Fisher calculates that the radial contraction of the globe has been .65 miles since its temperature was 4000° F., and 1.9 miles if its temperature were ever 7000° F. These calculated contractions are so slight that it is not worth while to calculate the surficial contraction which would result from them.[1] Certainly, if Fisher's conclusion is approximately correct, loss of heat by secular cooling is not even an important cause for crustal shortening.

Darwin,[2] as a result of a discussion of the strains of the crust resulting from secular cooling, concludes that an earth 8000 miles in diameter would contract so that "in 10,000,000 years, 228,000 square miles of rock would be crumpled up and piled on top of the subjacent rocks."

The variation in the estimates above given is so great that the question not unnaturally arises as to whether the truth may not be far from any of them. Indeed Darwin says, with reference to his estimate, that "the numerical data with which we have to deal are all of them subject to wide limits of uncertainty."

All of the foregoing calculations as to the amount of heat lost by the earth are based upon the hypothesis that the earth has not had a higher average temperature than 7000° F. during geological time, and also on the hypothesis that the entire loss of heat is by conduction. If the present temperatures deep within the earth are to be measured by *many* thousands of degrees, as some believe, the amount of heat lost would be much greater than calculated, and the resultant contraction correspondingly important. Also the process of cooling would have been much more rapid if convectional currents assisted, by means of which the hotter material comparatively deep within the earth continued for a long time to be brought near or to the surface. It has been customary to consider the heat lost through convection as so small as to be negligible, and all calculations upon the amount of heat lost by secular cooling have ignored this quantity.

[1] Physics of the earth's crust, by OSMOND FISHER: London, 1881, p. 72.

[2] Note on C. Davison's paper on the straining of the earth's crust in cooling, by G. H. DARWIN: Phil. Trans. Roy. Soc., Vol. CLXXVIII, Pt. A, 1887, p. 249.

Loss of heat by convection is accomplished through transfers of magma and transfers of water.

If calculations are made of the loss of heat due to vulcanism, upon the basis of the volcanic materials brought to the surface of the earth at the present time, it is highly probable that the conclusion would be reached that this quantity is so small that it might be ignored. But one must remember that present vulcanism is no criterion by which to estimate the transfers of material which have resulted during past great periods of regional vulcanism. The transfers of enormous quantities of igneous material by vulcanism from deep within the earth to its outer shell or to the surface of the earth, described on page 48, strongly suggests that convectional currents have been a more important factor in the process of secular cooling that has been supposed. A large part of the heat which is carried toward the surface of the earth by magmatic convection is transferred only a part of the way by the liquid rock. For, as seen (p. 49), the intrusive rocks probably equal or exceed in quantity the extrusives, and deeper transfers may have occurred of which we have no definite knowledge. From the place where the magma is stayed the heat is brought to the surface in two ways. First, a part is transferred by conduction through the overlying mantle of rock. That such conduction occurs is shown by the fact that the temperature gradients in many districts receiving hotter material are higher than the average. Second, another part of the heat is brought to the surface by convection through underground waters. In this case the transfer of heat begun by the magma and by conduction is continued by water.

This brings us to the second agent by means of which the earth is losing heat through convectional currents. Underground water circulation everywhere pervades the outer zone of fracture at the present time, and doubtless has since a solid crust existed. That heat is brought to the surface of the earth by water is self-evident in the various districts of geysers and hot springs.

But in estimating the amount of heat which escapes by convectional transfer by underground waters, it is not sufficient to con-

sider the random hot springs. If these were the basis of calculation it would indeed be unimportant. But if underground waters upon the average reach the surface with a slightly higher temperature than when they entered it, this may be a very important means by which heat is lost through convection. While difficult or impossible to prove by observation, I think it is unquestionable that underground waters must escape at a temperature upon the average somewhat higher than that with which they entered the earth. The average temperature of water when it enters the land may be presumably taken as that of the average of the surface of the earth at that locality. From this average temperature at the surface the temperature of the rocks increases downward. The vast quantities of water which at all times is taking an underground journey gains heat as a result of its contact with the warmer rocks. At another time I shall attempt to show that the water thus heated finally reaches the surface without losing all of the heat gained in its downward course. If this be so, there is constant loss of heat.

So far as I know, no attempt has ever been made to estimate the heat lost to the earth by means of the convectional underground currents of magma and water. While I am wholly unable to prove it, I have no doubt that the absolute quantity of such heat is enormous. The heat transferred by convection is to be added to the amount transferred by conduction.

As having an effect opposite to that of conduction and convection in lowering the average temperature of the earth, it is to be noted that as a result of changing rotation period (considered pp. 54–59) heat develops within the earth in two ways. First, heat is developed by tidal friction. Darwin states that he has "calculated that the heat generated in the interior of the earth in the course of the lengthening of the day from 5 hours 36 minutes to 23 hours 56 minutes would be sufficient, if applied all at once, to heat the whole earth's mass about 3000° F., supposing the earth to have the specific heat of iron."[1] Second,

[1] On the precession of a viscous spheroid, and on the remote history of the earth, by G. H. DARWIN: Phil. Trans. Roy. Soc., Vol. CLXX, Pt. II, 1879, p. 535.

consequent upon self-condensation, as a result of increased pressures coming from the greater effectiveness of gravity as the rotation period increased, additional heat within the earth would be developed. Also condensation of the earth as a result of change of physical state (see pp. 59–61) or in any other way, would result in the development of heat.

What the residual effect of these opposite neglected factors is upon the loss of heat as ordinarily calculated, it is impossible to say, and until the various estimates of the loss of heat approach one another more nearly than they do at present, it is not worth while to make a conjecture upon this subject.

If it be true that the temperature of the interior of the earth is much higher than premised in the calculations of heat lost during secular cooling, and if the convectional movements of magma and water are important means of refrigeration, it may be that heat has been transferred to the surface from much deeper within the earth than estimated by the physicists. Dutton[1] states that below "200 or 300 miles the cooling has, up to the present time, been extremely little." Davison affirms that below 400 miles the earth has not sensibly cooled.[2] These figures are based upon the hypothesis that the loss of heat is due wholly to conduction in a globe having a uniform initial temperature of 7000° F. If this hypothesis is incorrect, the hypothetical level of no lateral stress would be at a greater depth than calculated by Reade, Darwin, and Davison,— from 2 to 8 miles.[3]

Whatever the total loss of heat as a consequence of the various positive and negative factors, if we assume a liquid earth, it is certain that all of the resultant contraction is not available

[1] A criticism upon the contractional hypothesis, by C. E. DUTTON: Am. Journ. Sci., Vol. VIII, 1874, p. 120.

[2] On the distribution of strain in the earth's crust resulting from secular cooling; with special reference to the growth of continents and the formation of mountain chains, by CHARLES DAVISON: Phil. Trans. Roy. Soc., Vol. CLXXVIII, Pt. A, 1887, p. 235.

[3] Estimates summarized in Manual of geology, by JAMES D. DANA: 4th edition, 1895, pp. 384–385.

for crustal corrugations. None of the contraction is available to explain surficial deformation until after a solid outer shell has formed, either by solidification from the center or from the surface.

Also, making no hypothesis as to the early condition of the earth, the lessening of the solid surface available for corrugation does not include the full amount obtained by calculations based upon radial contraction. So far as the exterior shell was hotter than at present, its cooling would cause circumferential contraction, and consequent lessening diameter, without crustal corrugation, just as in the case of a steel jacket which in a heated condition is put upon the core of a gun, and which upon cooling shrinks.

Furthermore, as pointed out by Davison, the outer spherical shell might continue to contract circumferentially faster than the average contraction of the interior, because nearer the surface, and more rapidly losing heat.[1] This would cause tension in the outer part of the earth, just as in the case of the jacket on the gun, which, after it has shrunk to the core, continues to contract and so firmly clasps the core as to be under great tension; or just as a large steel ingot, at a high uniform temperature, by rapid cooling may so much more rapidly contract on its outer part than in its core as to form surface tensional cracks, because of the tensile stretching during the early stages of cooling.

How important this circumferential contraction is in the case of the earth is unknown. For we do not know the average temperature of the outer shell of the earth during early geological time, nor do we know very exactly its present temperature. We can only say that certainly some quantity must be subtracted from the total surficial decrease, resulting from loss of heat, in order to obtain the amount which is available to account for crustal shortening. Estimates which disregard this correction would be true only so far back in geological time as we can assume the temperature of the outer shell to be practically the same as at present.

[1] Loc. cit., pp. 231–242.

Also (as explained p. 53), so far as heat is lost by means of vulcanism the resultant earth contraction does not give an effect in crustal corrugations in addition to that due to the transfer of the magma.

But in estimating the effect of secular cooling upon corrugation, it must be borne in mind that the earth is so large that corrugations may have begun on one part of the crust, while other parts were still subject to tension, as explained, page 46. Under these circumstances corrugations might be produced which would be compensated by tensile cracks elsewhere. Such tensile cracks may become filled with sediment, with vein material, or with igneous injections. In so far as such compensated corrugations have been produced during the early history of the earth, these deformations are in excess of the amount which it is allowable to attribute to secular cooling. Davison suggests that early in the history of the earth the continental masses might have passed earlier from the stage of tension to the stage of compression than the sea beds, and that a part of the crustal flexures of the continents were, therefore, compensated by tensile fractures under the sea.[1]

It appears from the foregoing that the corrugations of the earth due to secular cooling follow from the difference in the loss of heat by conduction and by convection, and that developed by earth movements; and from an irregular distribution of the resultant stresses, which in some places may be tensile, and at the same time in other places be compressive. Ordinarily the loss of heat by conduction only has been considered. It is clear that in secular cooling we have an important, but probably by no means an adequate, cause to account for observed crustal deformation.

Vulcanism.—The second cause to which I shall appeal to explain shell corrugations is vulcanism.

At the outset it should be said that the quantity of igneous material which now reaches the surface of the earth is no criterion by which to judge past extrusions, for at times of regional

[1] Loc. cit., p. 241.

extrusions a quantity of magma may be emitted which surpasses the entire amount emitted between epochs of regional extrusions.

To appreciate the importance of regional extrusions of magma I need only to recall the Tertiary volcanic period, during which were produced the great lava plateaus, some of them thousands of feet in thickness, in western North America, Great Britain, Iceland, Franz Josef land, New Zealand, Abyssinia, and India. In western North America the area of these volcanics is to be estimated by hundreds of thousands of square miles. The Deccan traps of India are estimated to cover 200,000 square miles and for much of this area to be from 2000 feet to 6000 feet thick.[1] But the Tertiary volcanics with which we are acquainted are only a remnant of the quantity emitted; for during Tertiary and post-Tertiary times, the erosion has been stupendous, and a large fraction of the material extruded has been converted into sedimentary rocks by means of the epigene agents.

While the volcanic rocks of the Tertiary period surpass in quantity the known igneous rocks of any previous period, it by no means follows that previous volcanic extrusions might not have been on a still vaster scale. For the further back we go, the larger is the fraction of the volcanic rocks of any given period which has been converted into sedimentary rocks by the epigene agents, and, furthermore, the proportion of the volcanics of a given period which is buried under sedimentary and igneous rocks ever increases as time passes by, so that but a small fraction of the formations bearing extrusives of great age is exposed, and in these formations, as has been seen, the larger parts of the extrusives have been destroyed.

Moreover, the extrusives are probably but the smaller part of igneous rocks. In another place I have suggested reasons why intrusives are more extensive than extrusives.[2] For the

[1] Geology of India, by R. D. OLDHAM: 2d ed., Calcutta, 1893, pp. 256, 263.

[2] Earth movements, by C. R. VAN HISE: Proc. Wis. Acad. Sci., Arts, and Letters, Vol. XI, 1898, pp. 495–496.

present purposes it is not necessary to enter into this discussion, but I wish to recall the facts as to the dominance of intrusives. Intrusive rocks are discoverable only after a region has been eroded, and it is therefore in these denuded regions that we are to look for evidence of intrusion. Beginning with the older periods, and confining our attention to America, we find that the Archean, so far as we can ascertain its original character, consists largely of modified plutonic rocks. Passing to the Algonkian, hardly an area is found in which intrusive rocks do not occupy a large percentage of the area. This is illustrated by the great masses of intrusive rocks in the Lake Superior region, which in many districts occupy large fractions of the areas. In the Rocky mountain region, in various districts, the Algonkian sedimentary rocks are subordinate to the simply enormous quantities of intrusive granite and other rocks. This is well illustrated by the Pikes Peak district, where, according to Cross,[1] the intrusive granite occupies two-thirds or three-fourths of the entire area of the one-half-square-degree quadrangle, and where the Algonkian sediments are mere fragments; by the Black Hills; by the Medicine Bow mountains, and many other ranges. Passing to the Paleozoic and Mesozoic, in almost every mountain region there are enormous masses of intrusives. This may be illustrated by the great batholiths[2] of granite in the Sierra Nevada and in the New England regions, by the laccoliths of the Henry mountains, of the Elk mountains and La Plata mountains, and by irregular intrusions, sills, and dikes, in almost every mountain district in the country. As yet the known Tertiary intrusives in America are not so important, but in Great Britain, where denudation has gone far, a vast quantity of the Tertiary intrusives has appeared. Doubtless in America also, when denudation shall have advanced far enough, correlative with the volcanics mentioned p. 48 will be found a great quantity of intrusive rocks.

[1] Pikes Peak folio, by WHITMAN CROSS: Geol. Atlas of the United States, No. 7, 1894.

[2] Suess's term *batholith* is here used in its strict etymological sense, with no reference to any theory as to how the magma was transferred, or as to whether or not it occupied previously existing spaces.

What is true of the intrusive rocks of America is true of other regions of the globe. I have selected America as an illustrative continent, because I know the facts of the field better there than elsewhere.

Any terms which one can use must fail to convey an adequate idea of the stupendous quantities of magma which have been introduced into the outer shell of the earth, or poured out upon its surface. It is clearly impossible to make even an approximate quantitative guess of the amount of igneous materials which have thus been intruded and extruded during geological times. Its quantity is certainly to be measured in tens of millions of cubic miles, rather than in smaller units.

Now in this transfer of earth material two things have happened. In so far as it has been taken from the nucleus, it has lessened its bulk. By the amount the nucleus has been lessened, the bulk of the shell has been increased.

Of this great mass which has thus migrated from the nucleus to the shell, a large proportion has stopped before reaching the surface. This is only possible by extension of the shell either vertically or laterally, or both. The forms of intrusives clearly show that both have locally occurred. Sills and laccoliths have mainly found a place to occupy by vertical extension of the shell, although to some extent lateral extension of the intruded layers (see p. 15) is also produced by them. It is equally clear that volcanic necks, dikes, and batholiths have largely found space by local lateral extension, although it is not doubted that the intrusion of such forms is also accompanied by vertical extension, and in the case of batholiths an important amount. Necks, dikes, and batholiths have formed in cracks and crevices, and wedged the walls apart, thus locally extending the crust, and giving surface which may be used in lateral mashing or corrugations elsewhere. In many cases the mashing and corrugation, and consequent thickening and vertical extension, are immediately adjacent to the intrusives. This is most marked in the case of the great batholiths. Adjacent to such enormous masses as the batholiths which are found in the Black Hills, in

the Lake Superior region, in western Massachusetts, and in Great Britain, slaty or schistose structures parallel to the intrusives are common. These structures are conclusive evidence of lateral compression and vertical extension of the rocks intruded.

As already noted, the whole of the enormous mass of the intrusives and extrusives is to be subtracted from the mass of the nucleus and added to the mass of the shell. Of these two effects the expansion of the crust is without doubt by far the more important. If the nucleus of the earth be taken as having a radius of 3900 or more miles, radial contraction of one mile would involve a loss of volume of more than 190,000,000 cubic miles. A contraction of the radius of the earth of one mile, that is, from 3958.8 to 3957.8, would give a surficial lessening of only 100,000 square miles. In the supposed case of nucleal contraction of the radius by one mile, the 190,000,000 cubic miles of material would be available for additions to the crust. If it be supposed through geological time that this amount of material has been uniformly intruded within the outer ten miles of the crust of the earth, this would demand a surface space of 19,000,000 square miles, or about one-tenth of the earth's surface. As a consequence the material previously occupying this outer shell would be crushed so as to occupy nine-tenths of its original space, and this would involve enormous lateral crustal corrugation, with consequent thickening of the outer shell from ten miles to about eleven miles.

If it be supposed that the transfer through geological time from the nucleus to the outer five miles of the crust has been only one-tenth of the amount suggested in the above paragraph, the effect would still be great. Under this supposition, the radius of the nucleus of the earth as a result of igneous intrusions has contracted one-tenth of a mile, and as a consequence its surface has been lessened by about 10,000 square miles. This would involve an intrusion into the outer five miles of the crust of the earth of about 19,000,000 cubic miles of material, and I suspect that this is an underestimate rather than an overestimate of the igneous intrusions in this outer shell of the earth. Suppos-

ing that the igneous material is uniformly distributed vertically through the outer five miles, the material would occupy a surface space of about 4,800,000 square miles, with consequent surficial contraction and thickening of the remaining material of the crust. The surficial shortening of the original crust involved would in this case be about one-half as great as that due to secular cooling throughout geological time, as calculated by Mallet, and more than one and one-half times as great as that calculated by Dutton (see p. 41), even if it were supposed that the entire contraction were available for crustal corrugation.

Of course the above figures are hypothetical. The purpose of introducing them is to show the relative importance of crustal corrugation as a result of intrusion and nucleal contraction due to the transfer of magma, and to emphasize the fact that vulcanism is probably one of the great causes for shell corrugations, for two reasons. The intrusives occupy space in the shell. The nucleus shrinks by an amount equal to the combined igneous intrusions and extrusions. I am inclined to believe that this cause for crustal deformation is of the same order of magnitude as that due to secular cooling.

The fact that periods of considerable orogenic movements generally correspond with periods of great vulcanism is very suggestive and supports the conclusion as to the importance of the above transfers of igneous material, in explaining crustal corrugations. As a single illustration of this principle of correspondence may be mentioned the fact that the great Tertiary mountain-making period in which the Sierra Nevada range was last uplifted, in which the Coast Ranges and St. Elias Alps were formed, in which the Alps themselves were produced, and in which other mountain ranges were formed, is contemporaneous with the great Tertiary period of vulcanism.

By the foregoing I do not mean to imply that vulcanism is the initial cause of the orogenic movements. The initial causes are those assigned for earth contraction. The transfers of material followed as a result of the action of the initial causes, and thus is in a measure an effect, but also where the transfer

occurs this is a further cause for crustal corrugation. Thus the transfers of magma are both effect and cause of crustal corrugations.

So far as I know, Lyell[1] was the first to suggest that there is a connection between folding and igneous intrusions. However, Fisher[2] went further than Lyell, and urged that vulcanism is the chief cause of crustal corrugation. His argument may be very briefly summarized as follows: Fissures form "through metamorphic changes. When these fissures originated below and are propagated upward, they become filled with elastic vapor, and compression results." According to Fisher, it is the expansive force of the vapor which makes the openings, and consequent corrugations, and these openings are occupied by the magma. So far as my present purposes are concerned it makes no difference how the intrusives found places for themselves. I merely insist upon the fact that somehow great spaces formerly occupied by solid rocks came to be occupied by the magma.

Shaler[3] has also appealed to igneous intrusions as a cause for mountain-making, and in a manner similar to Fisher. He thinks that in many places of New England the dikes occupy from one-twentieth to one-tenth of the superficial area.

However, neither Fisher nor Shaler consider the shrinkage of the nucleus of the earth due to the loss of the magma for both intruded and extruded materials, or the crustal corrugation which must result from this transfer of material.

In closing this part of the subject, it should be noted that crustal corrugation caused by transfers of magma involves no contraction of the earth nor lessening of its surface as a whole, except as magmatic transfer results in loss of heat by convection, as explained (p. 43). It may also be remarked that the earth contraction due to loss of heat caused by actual transfers of

[1] Principles of geology, by CHARLES LYELL: 10th ed., London, 1867, Vol. I, pp. 134–135.

[2] Physics of the earth's crust, by OSMOND FISHER: London, 1881, pp. 185–207, and pp. 284–286.

[3] The crinetic hypothesis and mountain-building, by N. S. SHALER: Science, Vol. XI, 1888, pp. 280–281.

magma to within the crust or upon its surface is not a cause for crustal corrugation in addition to that produced by the transfer itself.

Cementation.—Another cause which explains crustal corrugation is cementation (see pp. 34–35). In this process material is carried in a direction opposite to the transfers of vulcanism. In the outer zone of disintegration and decomposition material is everywhere taken into solution by underground waters, and carried to the openings below, where a part of it is deposited. Although the zone of solution which supplies the material at any time is narrow, material never fails, because this outer zone is ever migrating downward. Wherever at moderate depth during the process of deformation openings form, unless they are occupied by magma, they are gradually filled by water deposits, and thus there is local lateral extension, as in the case of vulcanism. The amount of material which thus migrates downward by means of underground waters cannot be quantitatively estimated, but it is certain that it is enormous.[1] In many regions where much deformed, comparatively deep-seated rocks have been brought to the surface, it is found that a measurable, and in some cases a considerable percentage of the entire space was once unoccupied and has been filled by cementation. The cemented rocks thus become a unit, which may be later deformed themselves, or transmit the thrusts to adjacent rocks, which may be deformed. In either case the shortening of the original material is compensated, at least in part, by the extension due to the cement, and thus the crustal corrugations are partly explained by water transfers of material.

Change of oblateness.—Peirce[2] and Darwin[3] have shown that as a result of tidal retardation the speed of rotation of the earth is decreasing, and that in the far distant past it rotated much more

[1] Earth movements, by C. R. VAN HISE: Proc. Wis. Acad. Sci., Arts, and Letters, Vol. XI, 1898, pp. 511–512.

[2] The contraction of the earth, by B. PEIRCE: Proc. Am. Acad. Arts and Sci., Vol. VIII, 1873, pp. 106–108: Reprinted in Nature, Vol. III, 1871, p. 315.

[3] On the precession of a viscous spheroid, and on the remote history of the earth, by G. H. DARWIN: Phil. Trans. Roy. Soc., Vol. CLXX, Pt. II, 1879, p. 535.

rapidly than at present, at one time possibly as fast as once in five and one-half hours. During this time of changing rotation, assuming that the geoid has accommodated itself to its period of rotation in the past as at present, Peirce states that there was a "diminution of oblateness arising from the diminished velocity of rotation upon the axis." He concludes on the hypothesis of homogeneity, when the earth rotated 4.236 times as fast as at present, that the equatorial radius would have been about 2½ per cent. greater than at present.

Taylor[1] later calculated that "when the day measured but six of our hours, the equatorial radius (assuming a true ellipsoid of revolution, and neglecting the small amount of contraction by loss of heat) would have been about one-tenth greater than it now is, or 4359 miles, and polar radius about one-sixth less, or 3291 miles. In other words, the poles would have been about 658 miles nearer the center of the earth than they are at present, and the equatorial protuberance about 396 miles higher than at present."

The discrepancy between these two results is so great that I referred the problem, for re-solution, to Professor C. S. Slichter, whose paper on this and other points immediately follows (pp. 65–78). I further asked that he obtain the amount of surficial contraction which would result from the change of oblateness. Upon the hypothesis of homogeneity, and with a period of rotation of five and one-half hours, he obtains a result which is practically the same as that of Peirce's. He finds that the earth, instead of having a mean radius of about 3959 miles, would have a polar radius of about 3736 miles, and an equatorial radius of about 4076 miles. This change from the past oblate spheroid to the present oblate spheroid would involve a contraction of the surface of the earth of about 210,000 square miles.

Change of pressure.—It further occurred to me that when the earth rotated more rapidly, the centrifugal force was greater than at present. When the rotation was four time as rapid as at

[1] On the crumpling of the earth's crust, by W. B. TAYLOR: Am. Jour. Sci., Vol. XXX, 1895, p. 257.

present the centrifugal force at the equator would be sixteen times greater than now. This being the case, it is evident that the effectiveness of gravity in producing interior pressures in the earth must have been less than at present. If the pressures were less, other things being equal, the earth would have less density than at present, and thus by a steady increase in the effectiveness of gravity during the time of decreasing rotation, we have a cause for contraction of the earth.

After reaching this qualitative conclusion, I asked Professor Slichter to handle the problem quantitatively. He finds when the period was five and one-half hours, on the hypothesis of homogeneity, that the pressure at the center of the earth was 1,688,000 atmospheres, instead of 1,772,000 atmospheres, or 4.8 per cent. less. Following Laplace's hypothesis that the earth is heterogeneous, and increases from a density of 2.7 at the surface to 10.74 at the center, and supposing that the heterogeneous oblate spheroid had an eccentricity of .4, the same as the homogeneous spheroid which has a five and one-half hour period, he finds that the pressures at the center would be 2,920,000, instead of about 3,000,000 atmospheres, or 2½ per cent. less than now. Further, as suggested by Professor Slichter, if it be supposed that during the geological history of the earth there has been a steady change from homogeneity in the direction of heterogeneity, the pressures at the centers of the spheroid, instead of increasing by the small amounts given, might have increased a much larger amount, depending upon the amount of differentiation (see Fig. 2, p. 72). The extreme case would be a change of pressure from those at the center of the homogeneous oblate spheroid when the period was five and one-half hours, that is, 1,688,000 atmospheres, to the present pressures of the heterogeneous spheroid, 3,000,000 atmospheres. In this case the pressures would have been 43.7 per cent. less than at present. It is not supposed that any such change of pressure has occurred during geological time, but the truth probably lies somewhere between this amount and the minimum, 2½ per cent., and probably much nearer the latter amount than the former.

Calculating on the basis of a heterogeneous spheroid at the beginning, *i. e.*, upon the minimum change of pressures of 2½ per cent., and assuming Laplace's laws of the relations of pressures and densities, that "The variation in pressure in the interior of the earth is proportional to the variation in the square of the density" (see p. 75), Professor Slichter finds the surface would be two-thirds of 1 per cent. greater than at present, or 1,700,000 square miles larger.

Moreover, when the surface and volume were greater than the present amounts, the effectiveness of gravity in producing pressures would be less than assumed, because of the greater size of the spheroid, so that the estimated enlargement of the surface is short of the truth. However, it does not appear practicable to make a quantitative estimate of the value of this element.

Another estimate of the amount of surficial lessening as a result of increased pressure may be made by a different line of reasoning, as follows: The most probable conjecture which can be made as to the average density which the material of the earth would have if it could all be placed under conditions of ordinary pressure and temperature is that obtained by Farrington as the average specific gravity of meteoric falls, 3.69.[1] The material of the crust probably does not represent the average composition of the earth, for differentiation must have occurred to some extent, upon any hypothesis as to the origin of the earth. All inferences as to the composition of the interior of the earth are based upon a considerable number of hypotheses, none of which are verifiable. However, the meteoric falls, not the finds, give us the density of the material which is now being added to the earth. This is probably a better guide as to the average composition of the earth than the average of meteoric finds, as suggested to me by Professor Chamberlin, because the stony falls of the past have probably largely disintegrated. Of course it is not certain that the material added at present to the

[1] The average specific gravity of meteorites, by O. C. FARRINGTON: JOURN. GEOL., Vol. V, 1897, pp. 126–130.

earth from the interplanetary spaces represents the average composition of that out of which the earth segregated, but I can see no prospect that we shall be able to make any better conjecture of the average composition than that based upon meteoric falls. As already noted, the average specific gravity of such falls is 3.69, and the specific gravity of the earth is 5.67. Now, if this increased density is due to pressure, notwithstanding the high average temperature of the interior of the earth, it follows that the volume of the earth, as a result of pressure, has been reduced in the proportion of 5.67 to 3.69. The former number is 53.65 per cent. greater than the latter. If it be supposed that this percentage of expansion in volume would be inversely as the pressure at the center, a decrease of pressure at the center of 2½ per cent. would represent an increase of volume of 1.34 per cent., and an increase of superficial area of about 1,650,000 square miles. It will be noted that the above numbers are so manipulated as to give a minimum result. They could be handled in a different way and give a larger contraction of the surface.

The correspondence of this result with that obtained by Professor Slichter, 1,700,000, by an entirely independent line of calculation, is notable and suggests that Laplace's hypothesis as to the relations of pressure and densities within the earth, and the hypothesis that the average specific gravity of the earth material at ordinary pressures and temperatures is 3.69, and that the present density of the earth, 5.67, is due to pressure, may possibly both be approximately true.

The above calculations are based upon the hypothesis that the matter of the earth remains in the same condition under all pressures. It is subsequently seen that by a change from a liquid to a solid crystalline condition there is an important contraction. The increased pressure due to lessening rotation may have carried this change further than it would otherwise have gone. Gilbert has suggested to me that a moderate change of pressure within the earth may have acted similarly to the pressure upon a spring. Until the pressure reaches a certain amount but little deformation occurs, but at a certain stage a little

added pressure produces important deformation. In another place (pp. 8–9) in this number of the JOURNAL, Powell suggests that the modulus of compressibility varies under different conditions, and that so slight a change of pressure as that due to unloading and loading by denudation, has caused important expansion and compression. If this be so, so important a change of pressure as results from change of the rotation period of the earth might have produced a more important effect upon its volume than would be obtained by supposing the modulus of compression to remain the same under all pressures.

It is not supposed that the numerical results given (pp. 56–58) for surficial lessening of the earth due to increased pressure, following upon lessened speed of rotation, approach exactness. However, it is to be noted that the numbers obtained by two different methods are concordant, and moreover, that all of the hypotheses used in obtaining these numbers have been so made as to obtain minimum results rather than maximum, and they are therefore probably much too small. It therefore appears highly probable that crustal shortening resulting from increased pressure as the speed of rotation of the earth has lessened, is one of the chief causes for earth contraction.

Change in physical condition.—Another cause of the earth's contraction is the change in the physical condition of the matter of the earth's interior. In so far as liquid material has changed to a solid amorphous material, this has produced contraction. Further, if liquid or solid amorphous material has changed to a crystalline condition, this has resulted in more important contraction.[1] This contraction is supposed to be due to the closer arrangement of the molecules. According to Delesse,[2] in passing from the crystalline to glassy state, granite decreases in density 9 to 11 per cent., syenite 8 to 9 per cent., diorite 6 to 8 per cent., dolerite 5 to 7 per cent., and trachyte 3 to 5 per cent. Barus has shown in the case of diabase, an

[1] So far as I am aware, Lyell was the first to suggest that deformation might result from a change from a liquid to a crystalline condition. (Principles of geology, by CHARLES LYELL: 10th ed., London, 1867, Vol I, pp. 134–135; Vol. II, p. 236.)

[2] See Manual of geology, by JAMES D. DANA: 4th ed., 1895, p. 265.

average rock, that it expands 13 per cent.[1] in changing from the crystalline to a liquid condition. The reverse passage from the liquid to the crystalline condition would involve a contraction of more than 12 per cent.

Even if the earth is now solid and crystalline to the center, as believed by some geologists, it by no means follows that this was the case through the major part of geological history. If the changes above mentioned have largely occurred during geological time, this has been a very important cause for contraction. However, there is no way by which the amount can be quantitatively estimated without involving so many uncertain hypotheses that it is not considered advisable to make the attempt.

Another subordinate cause for contraction is a change from less complex to more complex molecules. In so far as this change is involved in that of change from a liquid to an amorphous state or from either of these states to the crystalline condition, it has already been counted; but as a result of chemical interactions all substances, even crystalline compounds, tend to rearrange themselves under given conditions, especially where the temperature and pressure are great, so that they will have the most compact molecules. In so far as this has occurred, it is a cause for contraction, although its importance cannot be assumed to be great.

These changes in the physical state of matter and the consequent earth contraction are independent of the numerical results due to change of pressure and loss of heat given on a previous page; for all the estimates in reference to secular cooling and changing pressure are upon the hypothesis that the matter continues in the same state. The loss of heat and the increase of pressure are undoubtedly among the causes which promote change of physical condition, but in so far as change of state has occurred the resultant contraction must be added to the quantities assigned to the amounts due to secular cooling and increased pressure.

[1] The contraction of molten rock, by C. BARUS: Am. Jour. Sci., Vol. XLII, 1891, pp. 498-499.

Loss of water and gas.—Finally, as suggested by Fisher,[1] nucleal contraction may have resulted from loss of originally occluded water. Chamberlin suggests that water and gas may have been emitted which have been lost to the earth.[2] Both of these losses would result in contraction of the nucleus. Probably the quantitative value of such contraction and consequent crustal shortening is small.

General.—Doubtless as the study of the earth continues, causes other than those assigned will be discovered for crustal shortening.

However, it is believed that the cumulative effects of the various causes assigned for nucleal contraction, and for crustal corrugation, are possibly sufficient to account for the phenomena of mountain-making.

We have seen that there are four important causes for crustal corrugation. These are secular cooling, vulcanism, change of oblateness, and change of pressures. Possibly there should be included among the important causes also that of change in physical condition and cementation.

It is impossible to make any accurate quantitative comparison of the several causes. However, it is to be noted that the change in surficial area due to oblateness of 210,000 square miles is about equal to that which Darwin estimated would result from secular cooling in 10,000,000 years, 228,000 square miles. It is to be further noted that the contraction due to increased pressures at a minimum estimation, 1,700,000 square miles, is 7½ times as great as the amount which Darwin estimated would occur in 10,000,000 years as the result of secular cooling, and is therefore equivalent to the effects of secular cooling for 75,000,000 years, or for a longer period than Darwin allows for the history of the earth since the separation of the earth-moon couple. At present we are, and probably we shall long continue to be, unable to give any accurate quantitative value to the crustal shortening

[1] Physics of the earth's crust, by OSMOND FISHER: London, 1861, pp. 87, 180, 218.

[2] A group of hypotheses bearing on climatic changes, by T. C. CHAMBERLIN: JOURN. GEOL., Vol. V, 1897, pp. 656–668.

resulting from vulcanism and cementation and from change in physical condition, but it appears possible, perhaps probable (see pp. 47–52), that in vulcanism we have an explanation of as large, or even a larger, fraction of the phenomena of crustal corrugations than is furnished by any other single cause.

The various causes for crustal shortening may be divided into two classes: (1) those which involve a change in the volume of the earth; and, (2) those which involve transfers of material. (1) The loss of heat due to secular cooling, the increased pressures due to lessening rotation, and the changes of physical condition involve a contractional change of volume. Changing oblateness due to changing rotation, vulcanism, cementation and nucleal loss of water and gas, involve no appreciable change of volume. (2) Changing oblateness is only possible by deep-seated transfers of material which cause a change in the form of the earth resulting in surficial contraction. Vulcanism results in crustal expansion and nucleal contraction, and therefore in crustal corrugation. The surficial expansion due to cementation compensates for a part of the crustal corrugation. Loss of water and gas produces slight nucleal contraction, and consequently some crustal corrugation.

Furthermore, it is to be remembered that the entire effect of all these changes is available to account for crustal corrugation, with the exception of contraction due to loss of heat, which, as explained (pp. 44–45), is only partially available to account for crustal deformation. Upon the other hand, the transfers of material by vulcanism from the nucleus to within the shell has an added effect in producing crustal corrugation much greater than that due to nucleal contraction.

The crustal shortening due to changing oblateness, and increased pressures resulting from lessening rotation must have been large in the remote past. According to Darwin,[1] 56,810,000 years ago the rotation period of the earth was 6 hours 45 minutes, and 46,300,000 years ago the period was 15 hours 30

[1] On the precession of a viscous spheroid and on the remote history of the earth, by G. H. DARWIN: Phil. Trans. Roy. Soc., Vol. CLXX, Pt. 2, 1897, p. 494.

minutes, *i. e.*, in about 10,500,000 years the period changed 8 hours and 45 minutes. For the entire 46,300,000 years which have since elapsed the change in period was from 15 hours 30 minutes to 24 hours or a change of 9 hours 30 minutes, but a little more than the change for the previous 10,500,000 years. At the present time, changing rotation has ceased to be a cause for mountain-making of any importance, for, according to Cayley,[1] the acceleration of the moon's motion due to tidal friction is less than 6 seconds per century.

The chief effects in mountain-making of changing oblateness and increased pressures resulting from change of rotation, as noted by Peirce in reference to the former, would be concentrated in the equatorial regions. The mountains are more numerous and higher at low latitudes than at high latitudes. The only way that this can be attributed to decreasing rotation is to suppose that the mountain-making localities were determined by the changes due to these causes, and that subsequent deformations have continued along the old zones of weakness.

However, decreasing oblateness and increasing pressures are available to explain the great deformation of the older rocks, and especially those of the Archean and Algonkian eras.

The amount of contraction which can be attributed to loss of heat is also a steadily decreasing quantity. However, in vulcanism we find a cause for crustal corrugation perhaps as potent now as at any time since the beginning of the Algonkian. Indeed, as has been seen (p. 48), the greatest volcanic epoch of which we have certain knowledge is late Tertiary time, and contemporaneous with this was the great Tertiary period of mountain-making.

It is clear that the explanation offered for crustal deformation is complex. The theory is a combined contractional and transfer theory. Moreover, the contraction, instead of being assigned to a single cause, secular cooling, is assigned to this and to increased pressure and changing physical condition. Also

[1] On the secular acceleration of the mean movement of the moon, by ARTHUR CAYLEY: Monthly Notices, Roy. Astr. Soc., Vol. XXII, 1862, pp. 171–230.

the transfers of material are of several kinds, but those of vulcanism and those of changing oblateness are the more important. The conclusions reached may therefore be considered as illustrating Chamberlin's method of multiple working hypotheses.

It is to be noted in conclusion that the argument of the above paper is independent of any theory of the origin of the earth, and of any theory of the condition of its interior, provided it is largely limited in its application to the time since the earth in some way had attained approximately its present mass. Furthermore, the contractional and corrugating effects dependent upon changing rotation involve the hypothesis that at one time the earth rotated upon its axis several times more rapidly than at present. If a more rapid rotational period be assumed than that discussed, the resultant effects would be correspondingly greater. But however the earth originated, and whatever the condition of the interior, the considerations offered which should be taken into account in estimates of crustal shortening are applicable.

C. R. VAN HISE.

NOTE ON THE PRESSURE WITHIN THE EARTH.

It is the object of the present paper to briefly consider the magnitude of the pressures within the earth-spheroid, especially as influenced by the changes that have been brought about in the ellipticity of the earth's figure by its changing rotation period.

Darwin, in considering the stability of the moon-earth couple, says it seems improbable that a rotation of the earth in a little over five hours, with an ellipticity of $\frac{1}{12}$, would render the system unstable, and it hardly seems likely that better data and more perfect solution would largely affect the result, so as to make the period of revolution of the two bodies in the initial configuration very much less than five hours.[1] If the earth be assumed homogeneous throughout, as was done by Darwin in his investigations, with a density equal to the present mean density, it is a simple matter to calculate the pressures within the earth for any given eccentricity of its outer crust; and these eccentricities are, in turn, easily deducible from a knowledge of the rotation period. A table on page 327 of Part II of Thompson and Tait's Natural Philosophy gives us at once the rotation periods corresponding to various values of the eccentricity. We there find that

$e = .5$ corresponds to a rotation period of 15,730 seconds or 4½ hours.
$e = .4$ corresponds to a rotation period of 19,780 seconds or 5½ hours.

I have assumed that the separation of the moon-earth couple took place at a time when the rotation period of the earth was intermediate to the values just given, and that it would be sufficient for the purposes of geology to trace, from the epoch indicated, the changes in pressure that have taken place in the earth's interior. If it be assumed that the spheroids of eccen-

[1] Phil. Trans., 1879, Part 2, p. 536.

tricities .5 and .4 had the same volume and mass as the present earth, the polar and equatorial axes can readily be computed. Using Clark's value of the mean radius and volume, 6.3709×10^8 cm. (3958.8 mi.) and 1.0832×10^{27} cc. respectively, and Baily's value of the mean density, 5.67, I obtain the constants as given in lines 5–8 of Table I. The change of shape from the spherical

TABLE I.

		Spheroid 1	Spheroid 2	Sphere	Units
1	Eccentricity $= e$.	.5	.4	0	
2	Ellipticity $= \epsilon$ ...	.134	.0835	0	
3	Mean radius $= a_0$	6.3709×10^8 cc.	$=$ 3958.8 mi.		
4	Volume	1.0832×10^{27} cm.	$= 2.5988 \times 10^{11}$ cu. mi.		
5	Surface.........	197,800,000	197,160,000	196,950,000	sq. miles
6	Excess of surface over that of sphere........	850,000	210,000		sq. miles
7	Semi-polar axis..	3597	3736	3959	miles
8	Semi-equatorial axis..........	4155	4076	3959	miles
9	Attraction at pole	995.6	990.2	981	dynes
10	Attraction at equator.......	968.8	975.0	981	dynes
11	Rotation period if homogeneous..	15730	19780		seconds
12	Centripetal acceleration at equator...........	106.7	66.16		dynes
13	Gravity at equator...........	862.1	908.8		dynes
14	Pressure at center if homogeneous	1.633	1.688	1.772	million atmospheres
15	Ratio to pressure at center of sphere........	92.2	95.2		per cent.
16	Pressure at center if heterogeneous	2.88	2.92	3.00	million atmospheres
17	Ratio to pressure at center of sphere	96	97.5		per cent.
18	Change of volume, Laplacian law...........	2.1	1.3		per cent.
19	Percentage change in area, Laplacian law.	1.34	8.5		per cent.
20	Actual change in area, Laplacian law...........	2,700,000	1,700,000		sq. miles

form requires, of course, a change in area of surface, which change is noted in lines 5 and 6 of this table. The change in shape of the spheroid would likewise change the values of the attraction of gravitation at all points of the surface. The value of the attraction at the poles would be greater than the mean attraction on the surface of the present earth, while the attraction at the equator would be less. These values are placed in lines 9 and 10 of Table I. The determination of the attraction has been made in terms of the eccentricity from accurate formulas.[1] The values could have been computed in terms of the ellipticity[2] from the following approximate formulas, in which the square of the ellipticity has been neglected:

$$\text{attraction at pole} = (1 + \tfrac{2}{15}\,\epsilon)\,g_o.$$
$$\text{attraction at equator} = (1 - \tfrac{1}{15}\,\epsilon)\,g_o.$$

Here g_o is the attraction at the surface of the same mass in spherical form.

It should be noted in this connection that the ellipticities of the spheroids under consideration are so large as to render the omission of their squares unsafe, although, as is the case in the present paper, no great importance is to be attached to the actual figures of the results. For a like reason, Clairaut's theorem may not be used with much accuracy in checking results.

Besides the reduction in the attraction at the equator due to the change in the shape of the earth, there was formerly a still further loss due to the high centripetal acceleration accompanying the short rotation period. In the case of $e = .5$, this amounted to 107 dynes, and in the case of $e = .4$ to 66 dynes; these values subtracted from the values of the attraction previously determined, give the value of equatorial gravity placed in line 13 of Table I.

The values of gravity and pressure at any point on the polar or equatorial axis of the spheroid may now be determined. If

[1] See PRATT's Figure of the Earth, 4th ed., p. 98.

[2] The ellipticity is the difference between major and minor axes divided by the major axis. I have represented it by the Greek ϵ, and have represented the eccentricity by e.

X_x represents the value of gravity at any point distant x from the center of the spheroid on an equatorial radius, and if Y_y represents the corresponding quantity for a point on the polar axis, and if g_e and g_p are the values of gravity at the equator and at the pole respectively, and if a and b are the semi-polar and semi-equatorial axes, then we have

$$X_x = \frac{g_e x}{a}; \qquad Y_y = \frac{g_p y}{b}.$$

Also if P_x and P_y represent the pressure at the same points, then

$$P_x = \frac{\rho_0}{2} g_e \left(a - \frac{x^2}{a}\right),$$

$$P_y = \frac{\rho_0}{2} g_p \left(b - \frac{y^2}{b}\right),$$

in which ρ_0 is the density of the homogeneous spheroid, and in which the other letters have the same significance as above. The following table gives the pressures at various distances from the center. The unit pressure is a million atmospheres of 10^6 dynes per sq. cm.

TABLE II.

PRESSURES WITHIN HOMOGENEOUS SPHEROIDS OF VARIOUS ECCENTRICITIES.

Distance from center along polar or equ. axis	$e=.5$	$e=.4$	$e=0$	Distance from center along polar or equ. axis	$e=.5$	$e=.4$	$e=0$
0	1.633	1.688	1.772	.6	1.043	1.079	1.133
.1	1.615	1.669	1.754	.7	.833	.862	.904
.2	1.567	1.618	1.700	.8	.588	.608	.638
.3	1.485	1.533	1.613	.9	.310	.321	.337
.4	1.370	1.417	1.488	1.0	.0	.0	.0
.5	1.224	1.264	1.328				

The pressures for $e = .5$ and for the sphere are shown graphically by the lower curves in Fig. 2. The line OX corresponds to either the polar or equatorial radius, as we may be pleased to consider it, but is represented, of course, as of length 10 in each case. The pressures at any other point in the spheroid can be found by drawing the equipotential surfaces; for on each of these the pressure is everywhere constant and equal, of course,

to the value of the pressure at the intersection of the equipotential surface with the polar and equatorial radii.

The pressures for $e = .4$ are not shown in the diagram, but they are not greatly different from those shown for $e = .5$. It should be noticed that the pressures for $e = .5$ are about 8 per cent. less than for the spherical form, and for $e = .4$ the pressures are about 5 per cent. less than for the spherical form.

The results above given were worked out on the supposition that the spheroid was homogeneous, having its density equal to the mean density of the earth. Of course the actual spheroid is not homogeneous, but heterogeneous, with the density increasing from surface to center. We know that the density of the surface material of the earth is approximately 2.75, and that the mean density is about twice as great. The exact law of variation of density in the interior cannot be said to be known, yet the law assigned by Laplace nearly a century ago is generally accepted as close to the truth. This law of density is as follows:

$$\rho = \frac{4.365\, a_0}{a} \sin \frac{2.4605\, a}{a_0};$$

in which ρ is the density of the stratum whose mean radius is a, the mean radius of the surface being a_0. The numerical constants are determined on the supposition that the surface density is 2.75 and the mean density twice as great. The variation according to this law is shown graphically by the heavily drawn curve of Fig. 3. An inspection of this diagram shows that the density increases quite uniformly for a considerable distance as we pass from the surface towards the center. We finally come to a central nucleus of nearly uniform density. The density at the center is 10:74.

The Laplacian law of density agrees well with the measurements of precession, and is probably as near to the truth as the measured values of the earth's mean density.

An exact method for determining the pressures within a heterogeneous spheroid without knowing its rotation period is not known to me. Even if the rotation period of the heteroge-

neous spheroids of eccentricities .5 and .4 were known, a computation of pressures would require the neglect of the squares of the ellipticities, which, in the case of ellipticities so large, would give results poorly compensating for the labor involved. I have, therefore, contented myself with two rough processes of approximation.

The pressure within a sphere in which the density is that of the Laplacian law can readily be computed by direct integration.[1] The result may be expressed as follows:

$$p = g_0 \, [2.7388] \left(\frac{\sin^2 n \, (2.4605)}{n^2} - 0.396 \right) \text{ atmospheres.}$$

In this formula, p is the pressure in atmospheres of 10^6 dynes per square cm. each, at the fractional distance n from the center of the earth, the radius being taken equal to unity for convenience. The bracket [2.7388] indicates the logarithm of a factor, and g_0 is the value of gravity at the surface.

Returning now to Fig. 1, it will be noticed that I have represented a section of the spheroid and two spheres, in contact at *N*. We shall suppose that the spheroid *A* is heterogeneous, with Laplace's law of density, and that sphere *B* is a sphere of same volume, same density, and the same law of density as the spheroid *A*. The sphere *C* is inscribed within the spheroid *A*, and has, I shall suppose, the same mean density and the same law of density as the latter. Then it is easy to see, since the law of density is such that the density increases towards the center, that the pressure at the center *O* of the sphere *C* must be less than the pressure at the center *O* of the spheroid *A*. Likewise, for the same law of density, the pressure at the point *O* of the sphere *B* is greater than the pressure at the center *O* of the spheroid *A*. The pressures at the point *O* within the spheres can be obtained by the formula above given, and as the pressure at the center of the spheroid is intermediate in value to those thus obtained, its value becomes approximately determined.

[1] See Osmond Fisher, Physics of the Earth's Crust, p. 32.

The pressures for the earth, calling the radius 10, are as follows, the unit being a million atmospheres:

Distance from center	Pressure in million atmospheres	Distance from center	Pressure in million atmospheres
0	3.00	6	1.25
1	2.94	7	0.85
2	2.74	8	0.50
3	2.46	9	0.21
4	2.09	10	0.00
5	1.67		

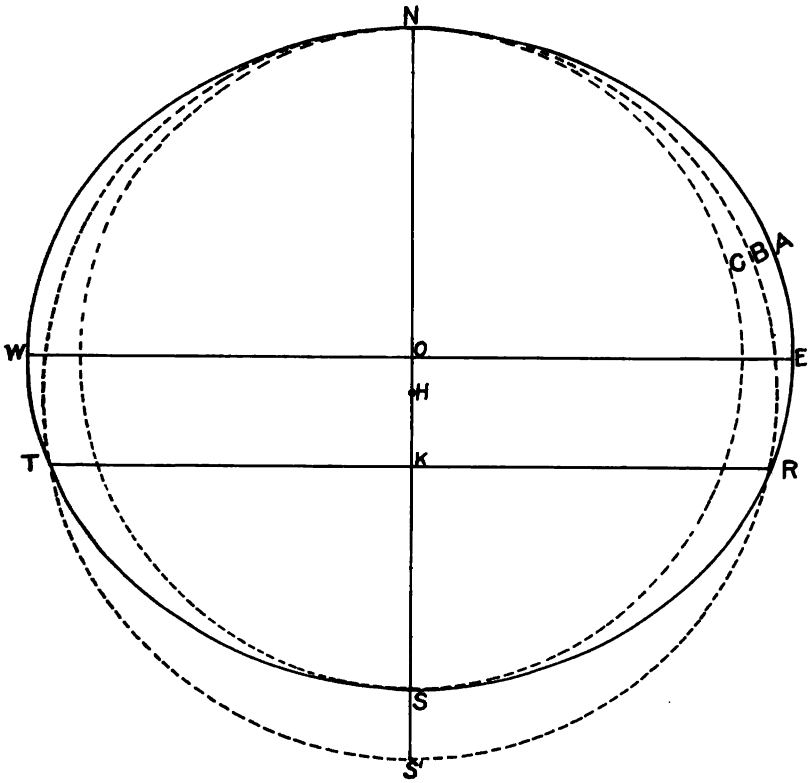


FIG. 1.

The pressures in the spheroid if $e=.5$ are about 4 per cent less, and if $e=.4$ are about $2\frac{1}{2}$ per cent. less than pressures

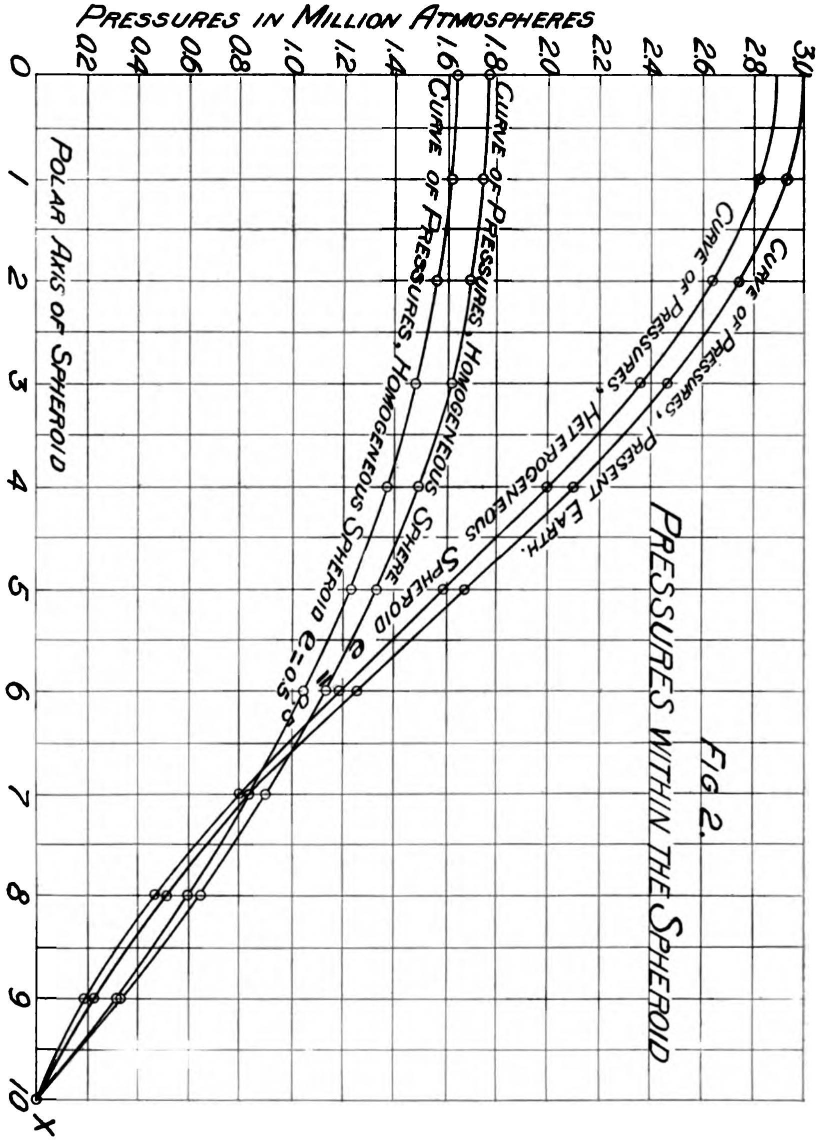

PRESSURES IN MILLION ATMOSPHERES
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0
0 1 2 3 4 5 6 7 8 9 10 X
POLAR AXIS OF SPHEROID
CURVE OF PRESSURES, HOMOGENEOUS SPHERE
CURVE OF PRESSURES, HOMOGENEOUS SPHEROID e=0.5
CURVE OF PRESSURES, HETEROGENEOUS SPHEROID
CURVE OF PRESSURES, PRESENT EARTH.
PRESSURES WITHIN THE SPHEROID
FIG 2.

FIG. 2.

in present earth. The pressures in the present earth and in the heterogeneous spheroid if $e=.5$ are shown graphically by the upper curves in Fig. 2. The greatest rate of change of pressures is seen to be at a point about .65 of the distance from the center to the surface.

Whatever the law of increase of density within the spheroid, provided only that the density continually increases as we approach the center, we may easily derive the following theorem:

The pressure at the center of a heterogeneous spheroid differs from the pressure at the center of the same matter in the spherical form, by a fractional amount which is less than two-thirds the ellipticity of the spheroid.

Thus if the ellipticity is .06, the pressure at the center will be not to exceed 4 per cent. less than if the matter was in the spherical form. This shows that the changes in pressure due to the changing ellipticity of the earth are limited in amount, although important, and of the same order of magnitude as the ellipticity.

Another roughly approximate method of estimating the pressures within the heterogeneous spheroid consists in assuming that all the strata of equal density have the same ellipticity as the surface. As a matter of fact, the ellipticity of the strata decrease as we approach the center by a law which may be deduced from the Laplacian law of density, and which is represented graphically by the broken line in Fig. 3. The ordinate of this curve gives the ratio of the ellipticity of a stratum to the ellipticity of the surface. It will be observed that the ellipticity of strata near the center is about 80.72 per cent. of the surface value. The actual case, then, does not differ from the assumed case of uniform ellipticity by a very large amount. It leads to the result that the change in pressure at the center of the earth due to a change in the ellipticity of the outer crust, is nearly the same in amount as if the earth were homogeneous, although the percentage change is much less than in the latter case. The relation between the ellipticity of any stratum to surface ellipticity is given by the equation :

$$\epsilon = \frac{2}{a^2}\left(1 - \frac{q^2 a^2}{3\,(1 - q\,a\cot q\,a)}\right)\epsilon_0$$

in which ϵ is the ellipticity of the stratum whose mean radius is a, ϵ_0 is the ellipticity of the surface, and $q = \frac{2.4605}{a_0}$[1]

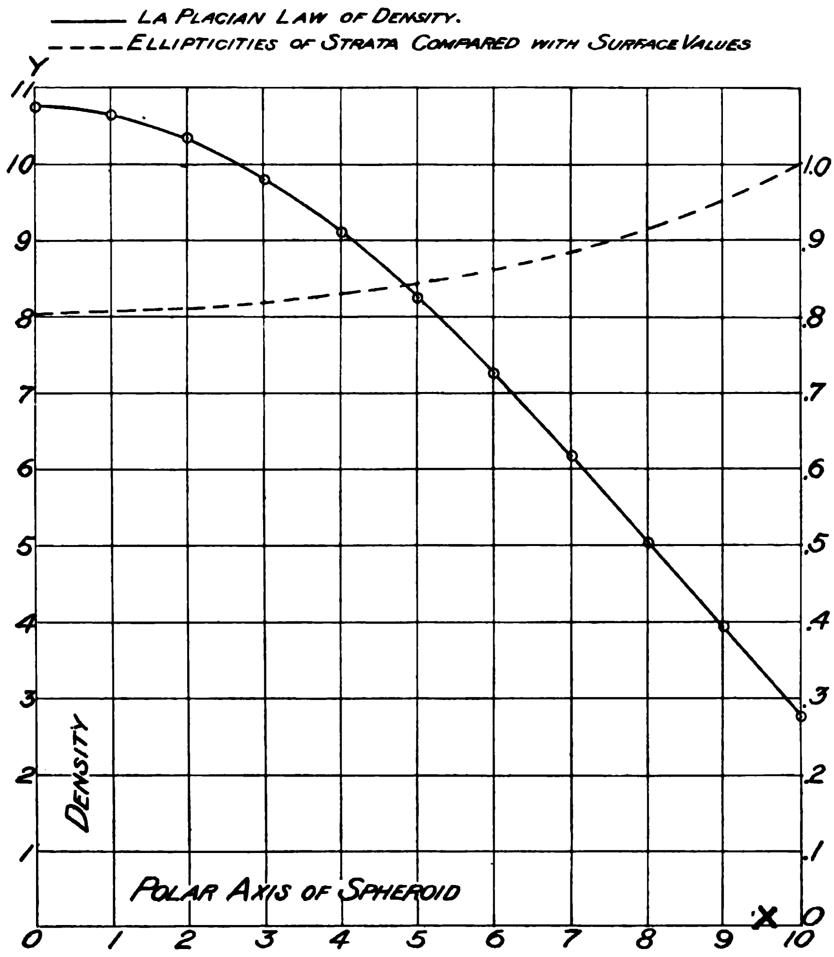


FIG. 3.

[1] See Thompson and Tait, II, p. 410; Pratt, Figure of the Earth, 4th ed., p. 115; Clarke, Geodosy, p. 84.

The decrease in the size of the earth that would be brought about by the increase of internal pressure discussed above, may be computed, if it be assumed that the high density in the interior of the earth is due alone to the compressibility of matter under the enormous pressures there present. Laplace, as a matter of fact, began by assigning a law of compressibility and thence deducing the law of density; however, his law of density might be close to the truth and yet be not entirely controlled by the pressure. The equation

$$\rho = 4.365 \frac{a_0}{a} \sin \frac{2.4605\, a}{a_0}$$

leads to the following relation connecting pressure and density.[1]

$$d\,p = k\, d\,(\rho^2)$$

or, as stated by Laplace: *The variation in pressure in the interior of the earth is proportional to the variation in the square of the density.*

The law of compressibility of gases — "Boyle's Law" — and the law of elasticity for small compressions in solids — "Hooke's Law" — state that the variation in density is directly proportional to the variation in pressure. Thus Laplace's law assumes a compressibility which is less than that given by either of the laws just named, an assumption which is, in itself, very reasonable.

From the above equation we derive

$$k\,\rho^2 = p + c$$

and determining the constants on the supposition that the surface density is 2.75, and the central density 10.74, we conclude that

$$(.02575)\,\rho^2 = p + .1947$$

in which p must be given in terms of a million atmospheres as unit. To determine the change in density due to a small change in pressure we may write,

$$\frac{d\,p}{p + c} = 2\,\frac{d\,\rho}{\rho},$$

or

$$\frac{d\,p}{p}\left(\frac{p}{p + c}\right) = 2\,\frac{d\,\rho}{\rho}.$$

[1] See O'Brien, Math. Tracts, p. 39; Pratt, p. 113; Thompson and Tait, II, p. 403.

Now if the change in pressure that has taken place is 4 per cent., we may place

$$\frac{dp}{p} = \frac{4}{100},$$

and, since c is small in comparison with p,

$$\frac{d\rho}{\rho} = \tfrac{1}{2}\frac{dp}{p} - n = \frac{2}{100} - n$$

in which n is a number with a small average value. Therefore, we may assume that, on the average, the change in density is about half the change in pressure. Taking the ratio as one-half, we can compute the change in volume of the spheroid for a given change in internal pressure, since, of course, volume is inversely proportional to density. I have placed results of this computation in the line 18 of Table I.

The decrease in the size of the earth due to the increase of internal pressures must likewise reduce the extent of the outer surface. If v and s represent the volume and surface of the sphere,

$$\frac{ds}{s} = \tfrac{2}{3}\frac{dv}{v},$$

or, for small changes, the change in surface is two-thirds the change in volume. This gives a reduction in surface amounting to about 1.3 per cent. for the spheroid $e = .5$, and .85 per cent. for the spheroid $e = .4$, or, in square miles, a reduction in surface of about 2,700,000 square miles, and 1,700,000 square miles respectively.

The compressibility of matter under high pressure and high temperature cannot be said to be known experimentally. Thompson and Tait, however, on page 415 of Part II, estimate for the average material at the surface of the earth, the compressibility that must theoretically follow from Laplace's law, and give as the result:

Melted lava, by Laplace's law - - 4.42

They also give actual experimental determinations of compressibility as follows:[1]

[1] If the radius of the earth, 6.37×10^8, be divided by each of these numbers and if

Alcohol	37.
Water	29.
Mercury	27.
Glass	5.0
Copper	8.1
Iron	4.1

The comparison, they remark, may well be considered as decidedly not adverse to Laplace's law. We may thus infer that it is far from unreasonable to hold that the high density of the interior of the earth is entirely due to the enormous pressures there present and hence it is not unreasonable to hold that the diminution in the earth's surface, pointed out above, has actually taken place. Yet, whatever future experiments may show in regard to the compressibility of melted rock, we certainly must believe that the enormous pressure at the center of the earth does have some effect, and, indeed, a large effect, in making the density high in that part of the interior.

In addition to the results which must follow from a former high rotation period of the earth and large ellipticity, important increments to the internal pressures must have taken place, if any change in the interior from homogeneity to heterogeneity has occurred. Notwithstanding the current computed results for the cooling of the earth, it seems reasonable to suppose that the energy in the interior of the earth, was, within geological times, distributed with greater homogeneity than it is at present. If any such change in the distribution of energy has taken place, then the density of the earth's interior has likewise progressed from homogeneity to heterogeneity. The curves given in Fig. 2 show that the pressure at the center of a homogeneous spheroid is only about half the pressure at the center of the present earth. Therefore, any progress that has been made

each quotient thus obtained be multiplied by 981 times the density of the substance, the result will be the *volume elasticity* in dynes per sq. cm. If the reciprocal of this last result be multiplied by 10^6, the result will be the *compression per atmosphere.* The numbers given in the table divided into the radius of the earth give what Thompson and Tait call the "lengths of the moduli of compression." See THOMPSON and TAIT, II, p. 225, § 689.

from homogeneity to heterogeneity would result in increased pressure in the interior, and in a decreased magnitude of the earth's volume and surface.

It is difficult to decide whether or not the minimum value of the eccentricity used above is too high to correspond with that uncertain date "the beginning of geological time." The rotation period of the heterogeneous spheroid would, probably, be shorter than for the homogeneous spheroid, and the shorter period may not be consistent with theories regarding the moon-earth couple. If we are required to assume a value of the eccentricity less than that used above, the changes in pressures I have given must be reduced. On the other hand, it must be remembered that there are causes at work which may augment the effects of a change in the internal pressure, and may even produce large results from what seem to be small causes. For example, if we suppose a contest in a given region in the interior between extreme heat on the one hand, and extreme pressure on the other hand, as to whether the material, or a single constituent of the material, will take on the crystalline form or not, we have a case in point. It may happen that a very slight increase in pressure may materially extend the zone in which crystallization may take place and thus result in a considerable increase in density; it is not impossible to believe that such a zone may exist in the region near the center, where pressures may be dominant on account of their enormous magnitude, and also in a region near the surface, where pressure may again be dominant owing to the lower temperature.

CHARLES S. SLICHTER.

THE GEOLOGICAL *VERSUS* THE PETROGRAPHICAL CLASSIFICATION OF IGNEOUS ROCKS.

THE rocks which make up the solid earth are of interest from a great many standpoints. A large part of geology is more or less directly concerned with them — as to their characteristics, their origin, their relationships in the mass of the earth, the changes in the rocks themselves, either metamorphism or decay, the mechanical destruction of rock masses, and structural changes in the earth dependent in many ways upon the characters of the rocks affected. From all of the points of view just indicated, and from still others, the geologist — often a specialist — has need for a nomenclature by which he may name the rocks as objects, and for various classifications expressing their observed relationships in different directions.

But while an adequate and expressive classification is a matter of great importance to many, it is commonly agreed that the systems of classification and nomenclature now in use are in a state of great confusion — of rapidly increasing confusion. To my mind the principal cause for this deplorable state of things is the lack of a clear conception of the natural relationship between *the systematic* classification of rocks, upon which their *specific* nomenclature must be based, and various *other, necessary* classifications of the same bodies. It seems that, while the multiform relations and affinities of rocks and their complex inner nature are more or less clearly understood, the futility of endeavoring to express all of these factors in one system of classification has not come sufficiently to recognition. It is my firm belief that no great progress in systematic petrography is possible until a more rational view of the relationship of that science to geology prevails among its devotees.

What is a rock? This question has often been found difficult to answer in satisfactory form. It is commonly said that

rocks are the materials which make up the crust of the earth, and to distinguish them from minerals it is pointed out that a rock is a geological body—a geological unit. But it is the unit of material or substance, and must be clearly distinguished from the geological unit of form or mass. It is the substance of the geological body, but the two conceptions are not coextensive. Chemical and mineralogical composition and structure are the chief characters of rocks as concrete objects, and it is well known that neither a stratum of sedimentary rock, nor a dike of igneous rock, is necessarily of the same composition or structure throughout. The rock unit cannot be that of the geological body as long as this is true. The rock unit is simply that which the systematic scheme of rock classification finds most desirable and practicable.

It is universally recognized that rocks not only have many relationships, when viewed from the geological standpoint, but that as objects they are extremely complex and variable in character. Lossen has said that the property of transition in all directions is an essential characteristic of the rock. It is quite possible that some who have struggled with systematic problems may be inclined to define the rock as the most variable and indefinite thing in nature! Yet rocks must be classified and named according to some system, and the task is none the less interesting or important because of the difficulties involved. The best system, that most nearly natural and logical, most uniform and stable, must ultimately prevail.

I understand that branch of geology which is concerned with rocks in all their aspects to be petrology—a treatise on rocks—and the narrower systematic, descriptive science of rocks as concrete objects, the basis for their specific nomenclature, to be petrography. This usage has now become so current in this country that discussion seems unnecessary.

Let us pass in review some of the different aspects of rocks which must be considered by the geologist, and at the same time we shall outline the field embraced by *petrology*. (1) There is the rock itself—an object of variable and complex character.

Its constitution — chemical, mineralogical, structural, and physical — must be studied and described. The differences or similarities exhibited by rocks in these respects lead to classes, groups, and lesser divisions, and the expression of these relations to a system of classification and a specific nomenclature. (2) The genesis of rocks is a subject of many phases. The source of materials, the agencies of transportation, the conditions of rock formation, each of these problems must be investigated in detail. (3) The geological occurrence embraces the formal relationships of rock masses to the earth and to each other. (4) The genetic interrelationship of rock types is one of the most difficult questions to deal with. (5) The metamorphism, and (6) the decay or destruction of rocks, each embraces a wide field. To these may be added other important lines of study. It is thus evident that petrology embraces several lines of research, each in some degree independent, each also related to the others. The results may be primarily of value as applied to the general science of geology — the history of the earth, or to the uses of the systematic descriptive science — petrography.

There has long been much discussion as to the objects of rock classification. It has been considered, on the one hand, as a mere mechanism upon which to base a nomenclature, and at the other extreme of view as a means chiefly for the expression of geological relationships of rocks. Mr. A. W. Jackson has said that nomenclature (meaning specific nomenclature) must be wholly divorced from rock classification. But that arrangement of rocks, in accordance with which they are described and their specific names are applied, is in itself the most important of all classifications, *the* systematic classification. The question is as to the criteria to be applied to produce this system. Here there must be general agreement with Mr. Jackson [1] in the proposition, often enunciated before, that a uniform and stable nomenclature must be based on facts and laws, not on theories and hypothe-

[1] On the General Principles of the Nomenclature of the Massive Crystalline Rocks, by A. Wendell Jackson, Amer. Jour. Sci. (3), XXIV, 1882, p. 113.

ses. Other classifications may use theoretical criteria and they will often serve useful purposes, nay, they are indeed distinctly necessary to the progress of petrology, but such arrangements must always be considered as subject to revision.

The criteria available for the systematic classification of rocks, fall into two groups, viz., the properties of the rocks themselves as objects, and their relationships to each other and to the earth, which is made up of them. There has always been conflict of views as to the use of these criteria in establishing a systematic classification. In the early years of this century there were two opposing schools, one represented by the German geologist, Werner, who classified all objects in the mineral kingdom as geological bodies, the other best represented by the French mineralogist, Haüy, to whom rocks were purely mineral aggregates. For present purposes it is not essential, however interesting, to trace the development of systematic petrography, but it is worthy of note that the geological classification of rocks is still most strongly advocated in Germany, and the mineralogical classification is still most nearly realized in France.

But the early systems of petrography failed necessarily because based upon ignorance. The material constitution of rocks was but very imperfectly known, and their geological relations were in many respects matters of crude hypothesis. All systems to the present time have failed for these reasons, and the systems of today are not free from the weaknesses due to the application of theoretical criteria.

If we review the situation as regards our present knowledge of the properties of rocks as objects it does not seem too much to say that the development of chemistry and mineralogy, and the application of the microscope to the study of rocks, have given us an accurate insight into their chemical and mineralogical composition, their structure and texture, which cannot be essentially modified by future discoveries. These are the properties universally recognized as most applicable for subclassification.

With respect to the geological relationships of rocks the case

is very different. Those rocks which are surface accumulations are so open to observation that we know many particulars of their origin—the sources of materials, the agencies by which the materials have been brought together, and the processes by which the rock has been made out of them. It is a curious fact that modern petrographers have done little toward formulating an adequate and logical classification and nomenclature for the rocks whose relationships are most evident, while they are continually extending, to an ever increasing degree of refinement, a systematic classification of igneous rocks upon foundations of theory or clear hypothesis. The fact that many criteria now used for the classification of igneous rocks are highly theoretical will hardly be questioned by anyone. From a philosophical standpoint it seems to me evident that such criteria cannot produce a stable system and must in consequence be rejected. A more detailed discussion of this question will follow.

Much has been said in recent years about the legitimate demands of geology upon systematic petrography. What are these demands? Clearly, both geology and petrography have certain reasonable demands to make, the one upon the other, but neither science has recognized its full natural rights, and hence has failed to state them properly. It is the unquestionable right of the geologist to demand of the petrographer a systematic classification of rocks, and a nomenclature expressing it, which shall be as natural and as stable as the controlling factors will allow. The petrographer must claim equal interest in such a system, and his logical counter demand is that he be allowed to construct that system through the application of the criteria best suited to produce the result desired. That is to say, he must reserve the right to reject hypotheses, theories, and even facts, if they are not adaptable.

It has often been said, from the time of the earliest classifications to the present, that rocks must be classified to express geological relationships. I believe that the geologist who today advances such a general proposition as a demand of geology upon systematic petrography is not in fact claiming his just

rights. Rather, it must be said that he does not recognize his rights. He does not perceive the true relationship between geology—petrology—and petrography. Nor does the petrographer who accepts that proposition recognize his rights.

Defining petrology and petrography, as has been done, bearing in mind the complex and variable character of the rock and its manifold relationships, it seems to me that the petrographer should esteem it his duty to produce a systematic classification of rocks with a consistent nomenclature, which shall first of all possess stability. The nearer it approaches to a natural system the better, but the character of the rock precludes the hope of securing a fully natural system. The right of the petrographer under this principle is that he may apply the test of adaptability to each criterion offered. It may be said by some that the ultimate object of petrography must be to secure a thoroughly natural classification, and that when knowledge of the rock is extensive enough such a system will be possible. I believe that that position is incorrect, if, by a natural classification, is meant one expressing all the relationships of rocks. It is not because of ignorance that we cannot set up such a natural system for rocks. The nature of the rock is the cause of this inability, not ignorance concerning it.

The petrologist must classify rocks from every standpoint. He must apply many material facts, all of which cannot possibly be used in the systematic classification of petrography, so many sided is the rock. To illustrate this point, a sandstone is a rock which may be described as inorganic, derived, compound, clastic, stratified, sedimentary, aqueous, surficial, noncombustible, etc., and each of these terms expresses a criterion that has been used in some proposed systematic classification. The petrologist must also classify some rocks on bases of theory or hypothesis, with an expressive nomenclature. For the good of his science he should be able to change such classification and dependent nomenclature as required by advancing knowledge. This amounts to a revolution if the general classification must also be revised in each case. Is it not then a logical principle, for the

good of all concerned, that the systematic classification of rocks, according to which their specific names are applied, must be based on their properties as objects, together with only such geological criteria as may be found adaptable, to the end that the system may be uniform, stable, and as natural as possible.

At this point I wish to digress for a moment and compare the task of the petrographer with that of the zoölogist, the systematic botanist or the mineralogist. From the beginnings of natural history, all natural objects have been subject to classification, at first on the most evident properties, and subsequently according to relationships. The modern zoölogist finds it possible to adopt nearly all of the general groups of animals early set up by the naturalist. Fishes, reptiles, birds, and other groups, needed only to be defined in scientific terms to bring general and scientific usage into harmony. The botanist has not been able to make his system correspond so closely to that of the naturalist. He has found that many natural groups of plants cannot be brought into his system, and he has wisely refrained from redefining the old names for those groups in such a way as to destroy their old and legitimate meaning. Thus trees (silvæ), shrubs, bushes, vines, evergreens, deciduous plants, and others, are not divisions of systematic botany, though recognized as useful and natural groups in the broader science of the vegetable kingdom. The properties and relationships of minerals may be nearly expressed in one system, but, as has been shown, rocks are of such manifold relationships that they defy a single system of classification to a much greater degree than plants.

If we now examine the schemes for the classification of rocks which have been current in the past few decades it appears that geological criteria have frequently been applied to produce the first divisions. It has been plain to all that rocks may be divided primarily into a few great classes on grounds either of geological occurrence or relationship, or of material properties. Each classification has its own justification, but the criteria to be applied in constructing a systematic scheme should plainly be those caus-

ally connected with the properties of the objects which are to be used in the further elaboration of the system. The geological agencies involved in the formation of the rock may be applied to produce rock classes differing in important material characters. This ground of classification has often been used, though not always logically carried out. It produces divisions both stable and natural. More or less distinctly the criterion of geological agency has been applied to form the classes called respectively the sedimentary, igneous and metamorphic rocks. Modern petrography has scarcely modified the old geological classification of sedimentary rocks, it has not yet anything which can be considered a system for metamorphic rocks, but it has elaborated a detailed scheme for igneous rocks, and it is now desired to review this system on the basis of the principles already presented.

Geological age has been commonly used as a criterion for the first subdivision of igneous rocks. It was originally applied in the belief that the older rocks differed in certain inherent and essential properties from younger ones. It was assumed that certain material characters were in some unexplained way governed by this geological factor, which thus became of prime classificatory value. But nearly all petrographers now perceive that assumption to have been unwarranted, and few would advocate a division of igneous rocks by age were it not for the double nomenclature in existence. It is difficult to agree upon the details of the simplification in this respect which all realize must eventually be effected.

It is in regard to the importance and applicability of geological form or place of occurrence and association of types as criteria for systematic classification that the greatest differences of opinion may be found among petrographers of today. The former of these factors, form or place of occurrence, has been and is still applied to the classification of igneous rocks on the ground that it is determinative of certain characters of rocks, and especially of structure, to a degree demanding recognition in this way. This usage is best represented by the well-known system of Prof. Rosenbusch by which massive or eruptive rocks

are divided into three great classes: "Tiefengesteine," "Ganggesteine," and "Ergussgesteine." These terms are commonly translated into English as Deep-seated rocks, Dike rocks, and Effusive rocks. Let us examine this classification from the different standpoints of the systematic petrographer and the petrologist.

To begin with it is self-evident that these class names express geological occurrence. They represent natural divisions of the geologist, they were used by him long ago and must be used in future, to express natural relationships. The geologist has a logical and practical claim upon these terms which cannot be denied. The question then is, can this geological classification be applied to the uses of systematic petrography, producing natural classes of rocks, a result which would be of great benefit to all concerned. I believe that it cannot be so used.

The system of Professor Rosenbusch is avowedly intended to meet the legitimate demands of geology upon his systematic science, as formulated by Lossen, to the effect that geological relations of rocks must be recognized as petrographical relations.[1] But while aspiring to meet the conceded demands thus expressed Rosenbusch has so redefined each of these grand divisions that it does not include all rocks belonging in it upon the criterion most clearly expressed in the name, the criterion the geologist must apply, and does include rocks that cannot logically be placed there. To illustrate by the most striking instance, the Dike rocks of Rosenbusch are not rocks occurring in dikes, which must be the geologist's definition, but rocks of as yet hypothetical derivative relation to certain other rocks. This class includes a small part of the rocks actually occurring in dikes and many not so occurring. Similarly the Deep-seated rocks of Rosenbusch are not necessarily abysmal. They appear in dikes and other intrusive bodies near the surface and even in some effusive masses. The Effusive rocks of this system occur in many intrusive masses and in the peripheries of deep-seated

[1] Über die Anforderungen der Geologie an die petrographische Systematik. Jahrbuch der K. pr. geol. Landesanstalt, 1883, p. 486.

bodies. That the above statements are true is abundantly admitted by Professor Rosenbusch in the pages of his "Mikroskopische Physiographie der massigen Gesteine."[1]

The classes of igneous rocks established by Rosenbusch upon the criterion of geological occurrence are not those of the geologist. But it is well understood by all familiar with the subject that an assumed relation between geological occurrence and structure of igneous rocks lies at the basis of Rosenbusch's inconsequent definitions of the three classes under discussion. In fact, the petrologist studying the genesis of igneous rock structures knows that they result from a complicated set of chemical and physical conditions attendant upon the consolidation of molten magmas. These conditions are as yet only partially understood. Pressure, absolute temperature, rate of cooling, the chemical changes in the fluid residue owing to fractional crystallization, the influence of so-called mineralizing agents, and several other factors, are recognized, but their relative importance is yet a matter of theory or hypothesis. A predominating influence was not long ago assigned to pressure, measured by distance from the earth's surface. But it is now known that that condition is in itself of little importance, within the zone of the earth's crust of which we have definite knowledge. It is also known that the conditions of consolidation are not controlled by either geological form or place of occurrence, to an extent capable of definite statement. The petrologist must recognize that while the typical granular structure is most common in abysmal igneous masses it may develop and is often found in the intrusive bodies of the intermediate zones of the crust and in surface masses. Nor has size of the molten body a determining influence. Neither are the porphyritic or fluidal structures dependent upon the geological form or place of occurrence of rocks exhibiting them.

Since the petrologist must inevitably apply the geological

[1] The natural limitations of the present discussion prevent an analysis of the considerations which led the German master to propose such a classification, but a review of the Rosenbusch system upon the principles here presented is now in preparation and will soon appear in this JOURNAL.

criteria of form and place of occurrence for the classification of igneous rocks into certain logical and natural groups, and has for this purpose a consistent language and mode of expression, he must surely demand of the systematic petrographer that these criteria shall not be used to produce another classification with other definitions of the same terms. Such a course produces confusion for which there can be no justification. It is to me utterly incomprehensible how the appropriation and redefinition of the geologist's terms and nomenclature can have been carried through as in the Rosenbusch system under the idea that thereby the science of geology would be benefited. And where is the science of petrography benefited by the formation of systematic groups which are confessedly unnatural and wholly unnecessary?

The petrologist must express the facts of the relationship between rock structure and geological occurrence, as between structure and other factors, to the best of his knowledge at any given time. It is not to his advantage to have this relation, always to be a matter of interpretation or theory to some degree, expressed in the systematic scheme. Nor can it be to the advantage of the system, for it will be a cause of instability.

The genetic interrelationships of igneous rocks, which most petrologists believe to be the result of what is called magmatic differentiation, are most important, but are clearly of hypothetical nature, and must remain at best matters of theory as long as the origin of the earth itself is veiled in mystery. It seems to me utterly impossible to admit such factors into the petrographic system. But it is the tendency of several leading investigators of today, notably of Rosenbusch and Brögger, to make these theoretical relationships more and more prominent in systematic classification, and from the considerations above presented I wish to make most earnest protest against this tendency as really contrary to the best interests of both geology and petrography. In thus protesting, I must not be understood as failing to appreciate the great advance in our knowledge of the origin of igneous rock varieties and of their structures, and

of the genetic relationships of types which has come within the past few years largely as a result of a promulgation of the theoretical ideas lying back of the systematic scheme advocated by Rosenbusch. One may well deny the desirability of the Dike rock group of Rosenbusch and be at the same time an ardent advocate of the theories upon which the group was established, and which have little connection with the fact of geological occurrence expressed in the name. Classifications of rocks, expressing working hypotheses as to their genesis, are necessary and may be set up at will if disconnected with the systematic classification. A stable nomenclature for rocks as objects will facilitate rather than hinder development of theoretical science.

I believe, then, that geological occurrence is not a practicable criterion for systematic classification of igneous rocks, and that it has been applied to that purpose through a misunderstanding of the true position of systematic petrography to the broader science of rocks. The petrographer has for many years failed to perceive, or, at least, to acknowledge, the right of the geologist to any special nomenclature of rocks. He has taken the time-honored terms of the geologist, redefined them to suit *his* own special purposes, until the geologist who is not a petrographer is almost afraid to use the simplest and most plainly denotive terms lest he be denounced as unscientific. But I maintain that it is the petrographer who has been unscientific, when he has misappropriated the natural nomenclature of the geologist, and when he has defined structural terms to express a genetic theory, or has applied them to certain rocks only out of all those possessing the structures in question. The definition of the granular structure as one having a certain mode of origin, instead of stating what the structure really is; the appropriation of *granulite* and *granite* for certain granular rocks, leaving no appropriate name for all rocks of that structure; the misuse of *porphyry* in analogous ways,—these are illustrations of thoroughly undesirable precision of definition, undesirable because at the expense of the geologist who has a prior and logical claim to these terms and needs them in their original senses.

RÉSUMÉ.—Rocks are too complex in their characters and have too many and too varied geological relationships to permit of one systematic classification expressing all their properties and relationships. A primary division on geological grounds may be carried through, producing classes of different characters, and such a division is universally advocated.

Since all the geological relationships cannot possibly be used in one system, it appears that a distinction must be made between that classification by which rocks are grouped for purposes of description and naming as concrete objects, and all other classifications. The former may be called the systematic classification, and I consider petrography to be the science presenting and applying that system to the description and naming of rocks. The broader science of petrology, using the nomenclature of petrography for specific purposes, must arrange rocks in as many other ways as are desirable to express their characters or relationships not introduced into the systematic scheme, and for the expression of these other arrangements a separate terminology is essential. It must not be appropriated under redefinition by the petrographer.

The material properties of igneous rocks afford ample criteria for establishing a systematic classification, and the use of geological relations is unnecessary. Since the geological factors of age, or of form or place of occurrence are not directly causes of the properties used in classification, they cannot be applied to produce coördinate groups. The attempts to thus apply them have been unfortunate. The justification of these attempts has been the belief that geology demanded that geological relations be recognized as petrographical relations. In the view above set forth this belief is illogical, and has resulted in injury both to geology and systematic petrography.

The impossibility of setting up an all-embracing natural classification of igneous rocks is not due to ignorance. It comes from the nature of the rock. The more we know the less shall we be able to include all relations in one classification.

WHITMAN CROSS.

ON ROCK CLASSIFICATION.

"To CLASS rightly — to put in the same group things which are of essentially the same natures, and in other groups things of natures essentially different — is the fundamental condition to right guidance of actions." These words of Herbert Spencer[1] may well form the introduction to this discussion, for they not only declare the importance of right classification, but state clearly in what it consists. It is because of the possibility of losing sight of its actual character in the approaching conflict over the reformation of rock nomenclature, that emphasis is laid at this time upon what seems to the writer to be the true character of rock classification. According to high authority[2] classification is "the act of forming a class or of dividing into classes." And further, a class is defined as "a number of objects distinguished by common characters from all others, a collection capable of a general definition."

To class rocks rightly would be to put in the same group or class those which are of essentially the same natures, or which may be distinguished by common characters from all others, and which may be capable of a general definition. This leads at once to a consideration of the nature of rocks and of the characters by which they may be distinguished from one another and which may be employed in their definition.

Nature and characteristics of rocks. — The origin or formation of rocks affects their nature to so great an extent, that it has been made a first basis for their subdivision, resulting in three categories: eruptive, sedimentary, and metamorphic. These, however, do not occupy the same position in the order of formation, but may be considered in one case as essentially primary, and in the others as secondary or derivative. The character of the rocks of these three categories, while possessing some points

[1] Man vs. State, p. 5. [2] The Century Dictionary.

of similarity, are, nevertheless, so diverse in others, and the laws of their relationships are so unlike, that it is advisable to consider them separately. The present discussion will be confined to rocks of the first category — that is, eruptive or igneous rocks.

The most distinctive features of any igneous rock are those inherent in the mass, namely, the chemical composition, the mineral composition, and the manner in which the constituents are grouped together — the texture and physical aspect of the rock.[1] Other characters of quite as essential natures are, however, less distinctive; such are the form or dimensions of the body of the rock and its formal relations to adjacent rock masses; that is, its body as a geological unit and its occurrence or habitat, and finally its connection or relation to other igneous rocks — its association — and hence its origin.

These two groups of characters are of different orders. The first are clearly material, having to do with the chemical elements and the minerals making the substance of a rock. The second are modal, having to do with forms and relationships among rocks. Failure to recognize this difference has led to confusion of ideas and of methods in classification and in didactic treatment. The rapid development of speculation along the lines of rock genesis in conjunction with the accumulation of many facts regarding the composition, occurrence, and association of igneous rocks, has prevented the proper consideration of these phases of the science apart from one another.

It seems necessary to call attention to a difference which in this science, at least, must always exist between a classification of the material under investigation — the rocks — and a treatment for purposes of instruction or of discussion of the whole subject of petrology, or of the rocks of any petrographical province.

It may be thought at this point that the writer's conception of a classification is too narrow and restricted, and that a system

[1] Cf. MICHEL-LÉVY, A., Structures et Classification des Roches Eruptives, Paris, 1889, p. 34.

of classification may be found, such that the two objects may be accomplished at one and the same time. It is the purpose of this paper to show that this is not consistent with the nature of the case, and that a classification of rocks and the didactic treatment of them cannot be based on the same method of procedure. In order to do this it will be necessary to consider: (1) the character of the constituents of individual rocks, both chemical and mineral; (2) the results of a study of the chemical composition of all kinds of igneous rocks; (3) the occurrence of these constituents in any rock as a result of processes of differentiation, according to generally accepted theories; (4) the chemical relations of series of rocks genetically connected; (5) the nature of a rock-body or geological unit; (6) the nature of rock-association, as in petrographical provinces.

The character of the constituents of igneous rocks both chemical and mineral.—The same chemical elements occur as constituents of nearly all igneous rocks. In the great majority of those analyzed oxygen, silicon, aluminium, iron, magnesium, calcium, sodium, and potassium occur in measurable proportions; while other elements, as phosphorus, titanium, manganese, barium, strontium, chromium, nickel, cobalt, lithium, zirconium occur in determinable amounts in many rocks, and in traces in others. In many cases their presence has not been sought. In numerous cases other elements are present in very minute quantities as shown by the frequent occurrence of alla nite containing the rare elements cerium, lanthanum, didimium.[1] Neglecting for the present elements commonly occurring in very small amounts, the eight elements first named are those which chiefly characterize igneous rocks. In very few cases one or two of these may be absent or in traces only, but in almost every case they are all present. Chemical differences among these rocks consist in the proportions in which all of these elements exist in each case. Hence a classification of igneous rocks

[1] CLARKE, F. W., On the Relative Abundance of the Chemical Elements, Bull. U. S. Geol. Survey, No. 78, 1891, p. 34. Also Bull. U. S. Geol. Survey, No. 148, 1897. See also ZIRKEL, F., Lehrbuch d. Petrographie, 2d ed., 1893, Vol. I, p. 648.

upon a chemical basis in nearly every instance is the grouping together of rocks that have like proportions of the same chemical elements.

The mineral components of igneous rocks are somewhat less constant in character than the chemical elements. Rocks occur that have distinctly different mineral components such as a granite with quartz, orthoclase and biotite, and a gabbro with labradorite, augite and hypersthene. But others occur having the same kinds of minerals in quite different proportions, such as a granite with much quartz and orthoclase and little biotite, and a syenite with much orthoclase and little quartz and biotite. Neglecting for the present the rarer or least abundant minerals that are found in igneous rocks, the characteristic ones are: quartz, feldspar, leucite, nephelite, sodalites, analcite, micas, pyroxenes, amphiboles, olivine, magnetite. Of these only one possesses a fixed composition, that is, quartz. Magnetite may contain a variable amount of titanium. Leucite, nephelite, and analcite may vary in the relative proportions of potassium and sodium present. Olivines differ in the proportions of iron and magnesium. While the others represent series of minerals grouped together on crystallographic grounds, but varying often widely in chemical composition. The feldspars embrace polysilicates with variable amounts of potassium and sodium, besides compounds assumed to consist of polysilicate and orthosilicate, varying in alkali metals, calcium and silicon. Micas, pyroxenes, and amphiboles present groups which are chemically still more variable. The chief mineral components of rocks then are not definite chemical compounds, but are substances that may vary within limits according to the proportions of the chemical elements in the magma from which the rock solidified. Moreover the same chemical elements appear in several of these minerals: oxygen in all, silicon in all but one, aluminium and the alkali metals in five, iron and magnesium in four, calcium in three and so on. Hence a change in the relative proportions of the chemical elements in a magma may affect nearly all of the mineral constituents.

The results of a study of the chemical composition of all kinds of igneous rocks.—In attempting a study of the chemical composition of all kinds of igneous rocks it was found necessary at the outset to devise some means by which the variations in the chemical analyses could be compared with one another graphically or by tabulation. It was also thought desirable to consider the chemical composition in its relations to the mineral composition, as far as possible. Further it was necessary to reduce the number of variable quantities to be treated in any one scheme. And for convenience and economy of labor the oxides of the metals were employed instead of the metals themselves, in all cases their molecular proportions[1] being used and not their percentages by weight.

In order to reach a basis for the correlation of the minerals and the chemical compositions of the rocks, the minerals may be divided into two groups, one embracing quartz, feldspars and the feldspathoid minerals: leucite, nephelite, sodalite, and analcite; all except quartz containing aluminium and the alkali metals or calcium, and being free from iron and magnesium. The other group contains the amphiboles, pyroxenes, micas, olivine, magnetite; all excepting magnetite containing magnesium as well as iron. Muscovite may be classed with the first group, but grades into biotite and may also be classed with the second group. The first group includes orthosilicates of aluminium and sodium, metasilicates of aluminium, sodium, and potassium, polysilicates of aluminium, sodium, and potassium, and free silica. In each case the ratio between alumina and the alkalis is a constant 1:1; except in the sodalites, in which soda is somewhat in excess of alumina. Calcium combines with aluminium in an orthosilicate molecule in which the ratio between the alumina and lime is also 1:1. This anorthite molecule combines with albite molecules so as to form a continuous series of compounds from orthosilicate to polysilicate. A consideration of the occurrence of these minerals in igneous rocks shows that quartz

[1] Found by dividing the proportionate weights of each oxide by its molecular weight.

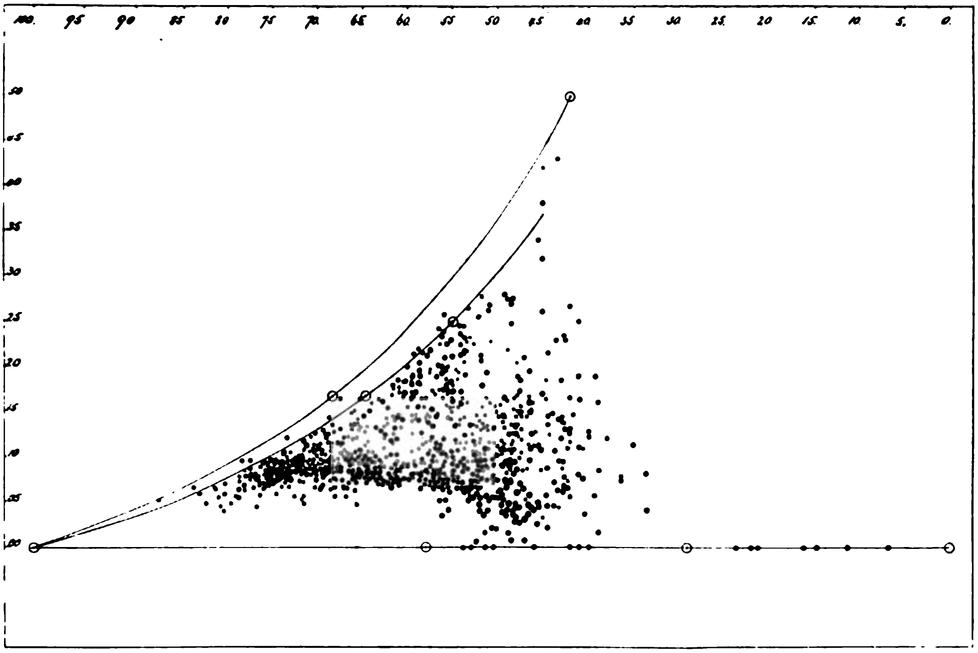


DIAGRAM 1.

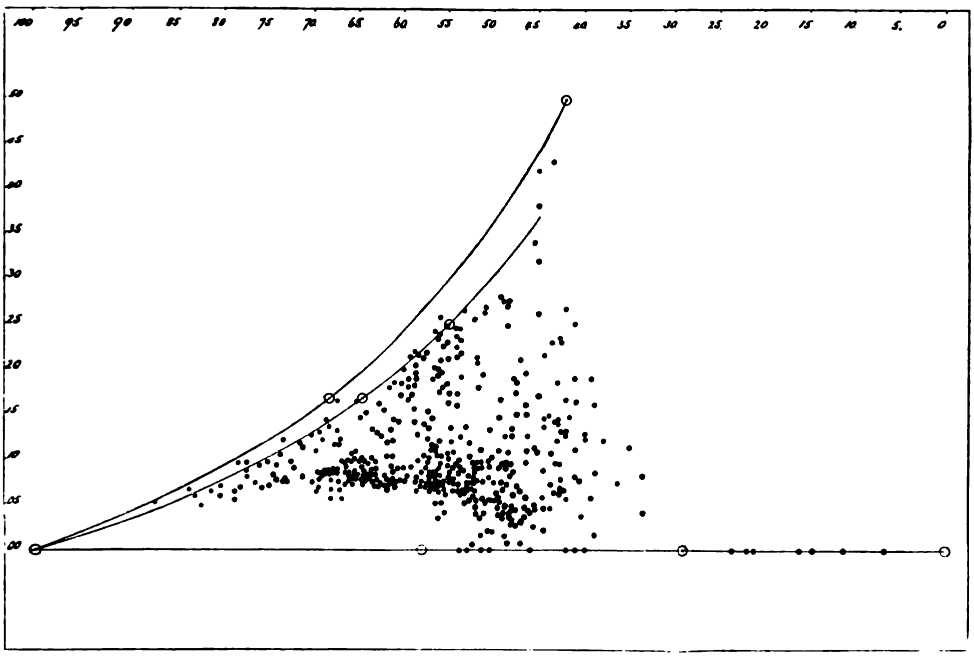


DIAGRAM 2.

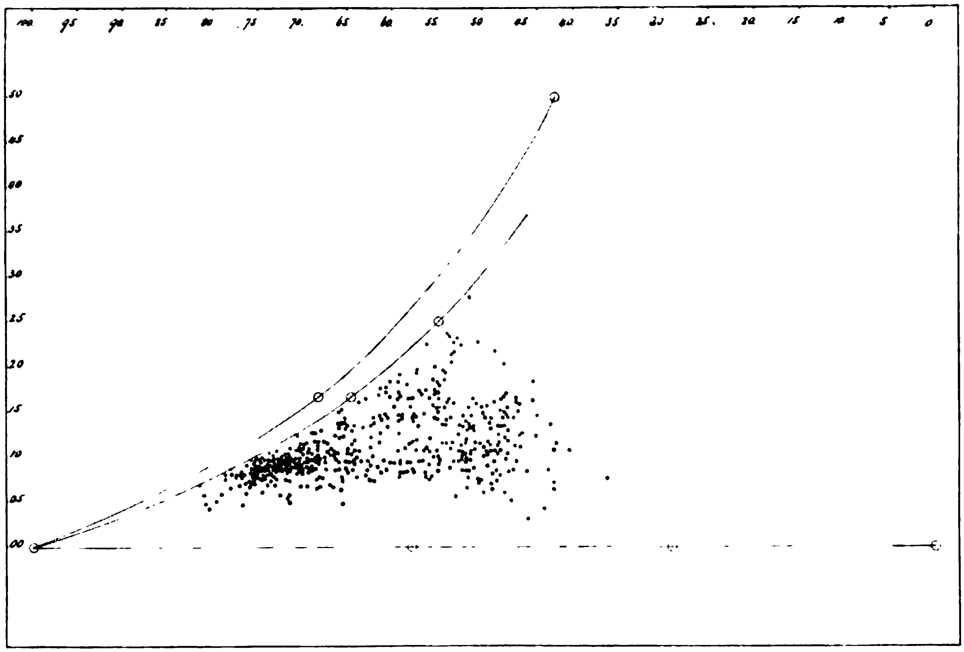


DIAGRAM 3.

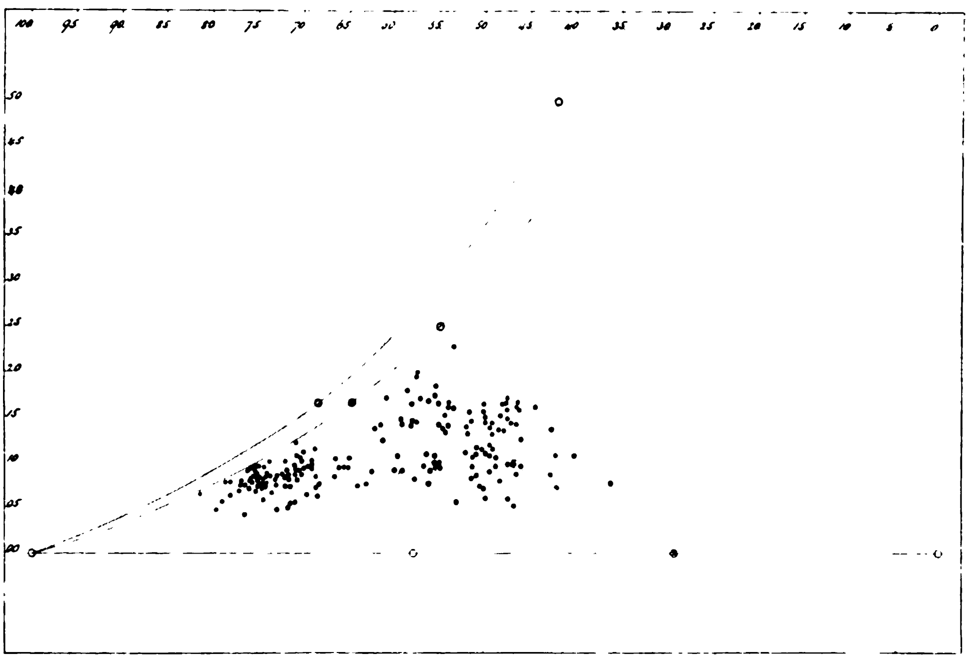
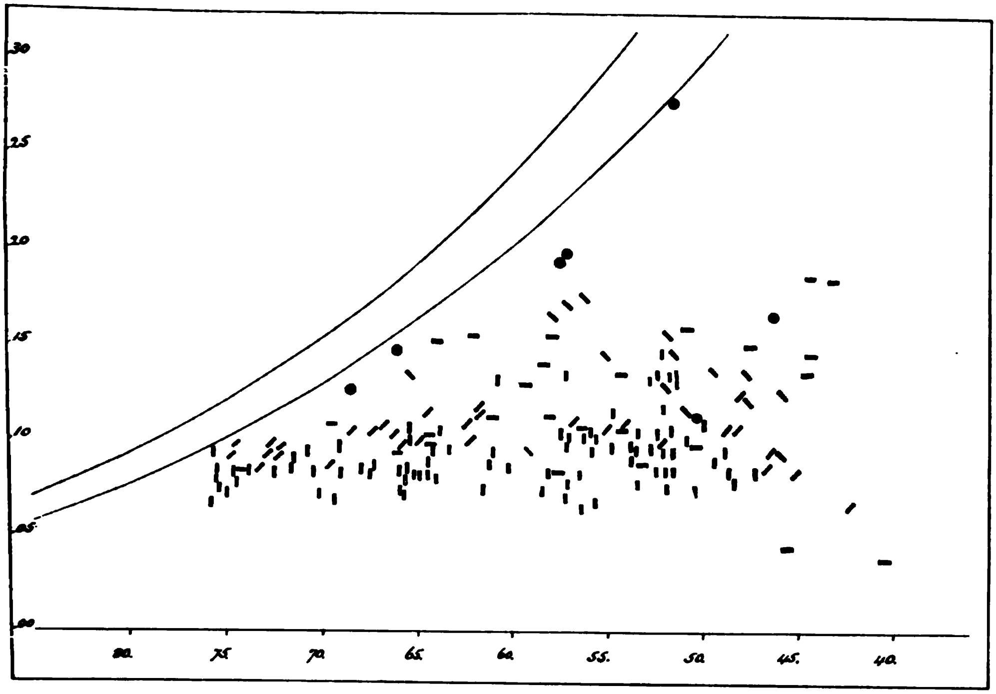


DIAGRAM 4.



Yellowstone National Park.
Crazy Mountains, Mont.
Little Belt Mountains, Mont.
Highwood Mountains, Mont.
Bearpaw Mountains, Mont.

DIAGRAM 5.

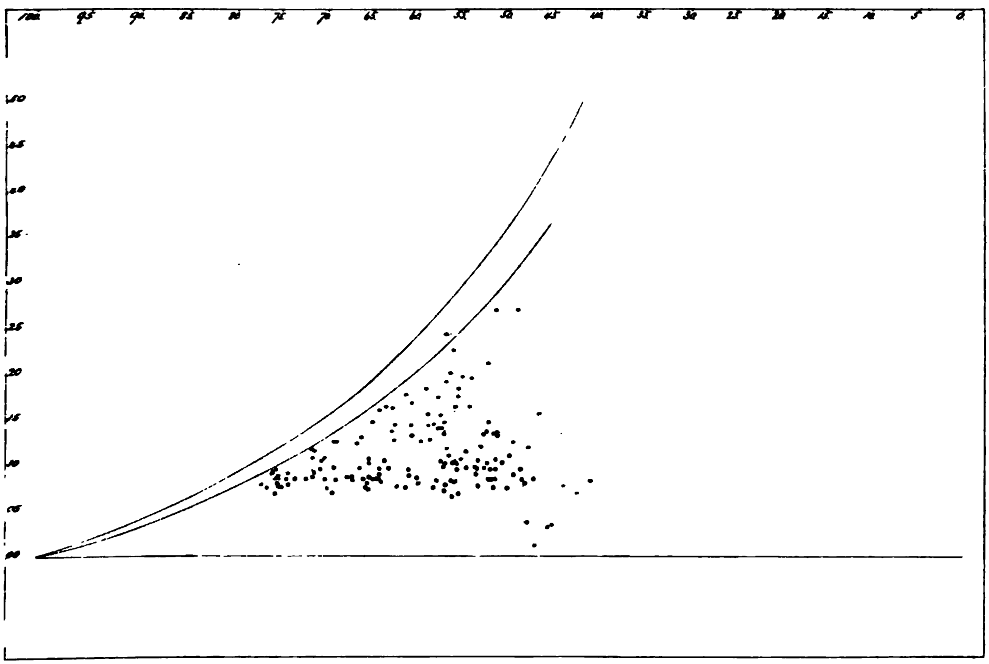


DIAGRAM 6.

does not occur with the alkali metasilicate or orthosilicate feldspathoid minerals. And these are found in rocks comparatively low in silica, the orthosilicate being most abundant in the least siliceous rocks. But quartz is found in variable proportions with polysilicate feldspars, usually in rocks high in silica. So that it appears to be a law that so far as the alkali-aluminous silicates are concerned the highest silicate forms which is possible with the available silica in the magma. Thus a close relationship exists between the amount of silica in the magma and the development of these ortho-, meta-, and polysilicates; as does also, quite naturally, the presence of free silica or quartz. No such evident relationship has as yet been discovered between the occurrence of the ferromagnesian minerals and the amount of silica in the magma.

Investigation also reveals the law, apparently of quite general application that to a great extent the alkalis in a magma control the alumina in such a manner as to compel it to enter a feldspathic mineral if possible,[1] so that a reasonable estimate of the amount of feldspathic constituents in a rock may be formed by reckoning the alkalis and alumina together with the available silica as alkali-feldspathic constituents. And while it is well known that the alkalis may enter abundantly into micas and to a less extent into amphiboles and pyroxenes, it seems to be the rule that they do not enter the two latter minerals to any considerable extent unless the alumina present in the magma is insufficient to form feldspathic minerals. The case of biotite is different and does not conform to the rule, necessitating some modification of it.

It seems true also that in a great majority of cases aluminium does not combine with calcium to form anorthite molecules unless there is an excess of alumina over the alkalis in the magma. Exceptions to this rule, of course, occur, but its appli-

[1] This assumption which has been used by the writer in his lectures as a working hypothesis for several years has also been advocated recently by MICHEL-LÉVY in his paper entitled Classification des Magmas des Roches Éruptives, Bull. de la Soc. Géol. de France, 3d series, Vol. XXV, pp. 342–343, Paris, 1897.

cation appears to be more general than was at first suspected; and by means of both laws a crude approximation to the composition of the feldspathic constituents in any rock may be obtained.

With regard to the occurrence of the minerals of the second group, it is a general law that they are most abundant in proportion to the diminution of silica and of the feldspathic minerals, so that an expression of the variations in these will also express inverse variations in the ferromagnesian minerals. To a very considerable extent the occurrence of the orthosilicate, olivine, and of the metasilicate, hypersthene, depends on the available silica in the magma, the former occurring in rocks with lower silica.

From these considerations it is evident that a comparison of the chemical composition of rocks may be undertaken so as to bring out the relations between the alkalis and the silica, and between these components and the feldspathic constituents, and that indirectly some notion may be had of the relations of the ferromagnesian constituents. Since two coördinates or variables only can be employed in a plane diagram or table, and a third involves a representation in three dimensions, or by some other device, it is necessary to reduce the factors to at least three. Those selected for the present investigation are, first, the silica on account of its important rôle in conditioning the character of the alkali-feldspathic constituents; second, the molecular ratio between the alkalis, soda, and potash, taken together, and the silica $\left(\frac{Na_2O + K_2O}{SiO_2}\right)$, for this corresponds to the relative proportions of orthosilicate, metasilicate, and polysilicate feldspar and quartz. The amount of silica in each case was made the abscissa and the alkali-silica ratio the ordinate, and since these quantities are not of the same kind, it is not necessary that the scale of parts should be the same for both. For convenience the amounts of silica were plotted directly from the percentages in each analysis. By this means it is possible to investigate the distribution of all the rock analyses studied with

reference to these two factors. A third factor may be expressed by inserting a number at the locus in the diagram of each rock analysis which shall indicate some other molecular ratio, such as that of the approximate feldspar

$$\left(\frac{Al_2O_3-(Na_2O+K_2O)}{2\,(Na_2O+K_2O)}\right)$$

Or in another case the molecular ratio between the ferrous oxide, magnesia, and the lime not calculated with the anorthite molecule, and the silica.

$$\left(\frac{FeO+MgO+CaO-(Al_2O_3-[Na_2O+K_2O])}{SiO_2}\right)$$

The comparison by the method just indicated of 928 chemical analyses of igneous rocks has given rise to the accompanying diagrams. The analyses were selected with care in order to avoid those of much altered rocks, or those likely to be untrustworthy. The greater part have been made by chemists of the U. S. Geological Survey, which has furnished the most considerable contribution to the knowledge of the chemistry of rocks ever made by any organization. The analyses include those of all known kinds of igneous rocks that have been analyzed, so far as the writer has encountered them.[1]

Diagram 1 shows the distribution of all the analyses, the black spots representing those in which soda is more than twice the potash molecularly; the red spots those in which it is less than twice the potash. Diagram 2 is for all those in which the molecular ratio of soda to potash is greater than 2, $-\frac{Na_2O}{K_2O}>2$. Diagram 3 is for all those in which this ratio is less than 2, $-\frac{Na_2O}{K_2O}<2$. Diagram 4 is for those analyses in which this ratio is equal to or less than 1, $-\frac{Na_2O}{K_2O}\leq L\,1$. One of

[1] The analyses have been taken from the following sources: Analyses of Rocks and Analytical Methods, Bull. 148, U. S. Geol. Survey, 1897. Analyses in papers published by PIRSSON and WEED. ROTH's tables of rock analyses. BRÖGGER's publications, and many others.

the most notable features of Diagram 1, is the evident limitation of the range of alkali-ratios along the curved lines. These lines were suggested by the distribution of analyses in the diagram and represent in one case, the upper line, the possible range of analyses for rocks consisting wholly of silica, alumina, and soda, the two last elements being always in the proportion of 1 : 1; corresponding to nephelite at one extreme, succeeded by a mixture of nephelite and a possible metasilicate of these bases, or of nephelite and albite, and of albite and quartz, and finally of quartz alone. In the case of the lower line the curve corresponds to a possible range of analyses for rocks consisting of silica, alumina, and potash, the latter being in the proportion of 1 : 1. The mineral range would be from pure quartz, through a mixture of quartz and potash feldspar, to one of potash feldspar and leucite, to a possible orthosilicate of aluminium and potassium, corresponding to a potassium nephelite. In not a single instance is the sodium-aluminium limit transgressed, and only a few cases occur beyond the potassium limit. The rocks actually consist of the minerals just named. A nearly pure nephelite rock exists as urtite from the Kola peninsula,[1] and as portions of the nephelite-syenite of Dungannon township, Canada, described by Professor F. D. Adams.[2] A nearly pure albite rock has been found in California, by Mr. H. W. Turner.[3]

The fact that these limits are so closely approached, but never transgressed, is a clear indication that the alkalis do not exist in greater proportions than may satisfy this series of ortho-, meta- and polysilicate molecules. There are instances, however, in which part of the requisite alumina is replaced by ferric oxide.[4] There are a few cases in the neighborhood of

[1] RAMSAY, W.. Urtit, ein basisches Endglied der Augitsyenit-Nephelinsyenit-Serie, Geol. Fören. i Stockholm Förhandl,— Bd. 18, Häft 6, 1896, p. 459.

[2] ADAMS, F. D., On the Occurrence of a Large Area of Nepheline-Syenite in the Township of Dungannon, Ontario, Am. Jour. Sci., Vol. XLVIII, July 1894, p. 10.

[3] Further Contributions to the Geology of the Sierra Nevada, 17th Ann. Rep. U. S. Geol. Survey, Washington, 1896, p. 728.

[4] The most marked exception to this rule is the group of rocks from Leucite Hills, Wyo., described by CROSS, Igneous Rocks of the Leucite Hills and Pilot Butte, Wyoming, Am. Jour. Sci., Vol. IV, 1897, pp. 115–141.

these limits in which alkalis are in excess of the alumina, when sodalite minerals abound;[1] and others in which alumina is in excess, when muscovite forms. From the foregoing it appears that if differentiation has taken place to produce these magmas there has been no considerable accumulation of alkalis independently of all other constituents. And from the approach to the pure nephelite molecules by sodium magmas, and from the limitations of the potassium magmas in the neighborhood of the leucite molecule, there is the strongest indication that the differentiation of the magmas affected molecules more complex than simple oxides of potassium and sodium, and probably as complex as silicates of aluminium and sodium or potassium, corresponding to known mineral molecules. However, as already stated, there are proofs deducible from the laws of crystallization that the molecules in molten magmas are not stable or fixed, and the aluminium and potassium, for example, may enter orthoclase, leucite or biotite according to circumstances in the form of ortho-, meta- or polysilicate.[2]

In the direction of the maximum limit of silica, there are rocks consisting of alkali-feldspars and abundant quartz, which may grade into pure quartz, as suggested by Lehmann[3] and Howitt;[4] certain quartz veins being eruptive and extreme forms of aplitic intrusions. Thus the oxide molecule, SiO_2 appears to be capable of separation by processes of differentiation from other silicate molecules. If analyses had been made from these rocks, the diagrams would have shown a distribution of analyses as far as 100 per cent. of silica. The minimum limit of silica should occur in connection with differentiation products free

[1] WEED, W. H. and PIRSSON, L. V., The Bearpaw Mountains of Montana, Am. Jour. Sci., Vol. II, No. 9, 1896, p. 197.

[2] IDDINGS, J. P., The Origin of Igneous Rocks, Bull. Phil. Soc., Washington, Vol. XII, 1892, p. 176.

[3] Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, etc., Bonn., 1884, p. 55.

[4] Notes on the Area of Intrusive Rocks at Dargo, Trans. Royal Soc., Victoria, 1887, Vol. XIII, p. 152. Also Notes on Certain Metamorphic and Plutonic Rocks at Omeo, p. 10.

from silicate minerals, such as certain iron ores[1] whose analyses occur at the extreme lower right hand corner of Diagram 1. From these it is evident that molecules of iron oxides may separate by differentiation from silicate molecules. The maximum limit for soda will be when the soda-silica ratio is 0.5, that is when $NaO_2 = 21.75$ per cent. and $SiO_2 = 42.10$ per cent. The maximum limit for potash will be when the potash-silica ratio is 0.25, that is when $K_2O = 21.51$ per cent. and $SiO_2 = 54.92$ per cent. Both alkalis sink to a minimum of zero in certain kinds of peridotites, pyroxenites, and in certain eruptive iron ores. They may disappear in anorthosite composed of pure anorthite.

The limit of distribution of analyses toward low silica appears to be a line which would correspond to a variable mixture of the lowest alkali-alumina silicate — nephelite for soda magmas, and leucite for potash-magmas — and the least siliceous ferromagnesian silicate, fayalite. This limit will probably be modified when series of rocks are analyzed grading from gabbros to the iron ores. The range of variations in the proportions of iron oxides, magnesia, lime and alumina, does not appear in these diagrams.

In this connection it may be pointed out that the variations in all of the chemical constituents, other than silica, must increase in proportion as silica decreases. When 75 per cent. of the magmas is silica, only 25 per cent. remains for other constituents, but when there is only 40 per cent. of silica, 60 per cent. must consist of other compounds. It is known that rocks high in silica contain much more alumina and alkalis than other constituents, hence the variation in these other constituents cannot be great. The greatest variation occurs when part of the alumina is replaced by ferric oxide. But in rocks low in silica there is no general law controlling the other constituents, which may, therefore, vary widely in different rocks. Consequently the number of different kinds of rocks possible

[1] VOGT, J. H. L., Bildung von Erzlagerstätten durch Differentiationsprocesse in basischen Eruptivmagmata, Zeitschr. für prakt. Geol., Berlin, 1893, Jan., Apr.

for any given percentage of silica is much greater the lower the percentage of silica.

Diagram 1 shows that within the limitations above mentioned there are nearly all possible transitions in relative proportions of alkalis and silica, and the same is true for other constituents. Diagrams 2, 3 and 4 show that the range of alkali variation is greatest for rocks in which the ratio of the soda to the potash is greater than 2, and least for those in which it is less than 1. That is, it is greatest for distinctly sodic rocks and least for those very rich in potash.

While there is a clustering of analyses in the parts of the diagrams corresponding to lower alkali-silica ratios, there are no loci of specially marked aggregation, except toward the most siliceous end of the more potassic groups, and no such clustering as to suggest natural subdivisions of the analyses on any chemical basis. A chemical subdivision must be an arbitrary one, making breaks in continuous series. Comparison of Diagrams 2, 3 and 4 shows that the most siliceous rocks are generally richer in potash than in soda, also that the rocks in which alkalis decrease to nearly zero contain much more soda than potash. Those parts of the diagrams in which few analyses occur will undoubtedly be filled up as more rocks are analyzed.

It is to be noted that analyses occurring in close proximity to one another in these diagrams, and nearly alike in percentages of silica and alkalis, may in some cases differ more or less widely in other respects, so as to belong properly to different classes of rocks. They are by this method of comparison the more strongly contrasted and their essential differences more clearly recognized. This method of comparison brings closely together rocks agreeing in chemical composition, but often differing in mineral composition and physical characters, and having quite different names, and in this way emphasizes the necessity for improved definitions of names already in use and for the creation of a systematic nomenclature.

The occurrence of these constituents in any rock as a result of proc-

esses of differentiation according to generally accepted theories.—A study of the crystallization of rocks has shown[1] that different minerals and combinations of minerals may form from magmas chemically alike, according to physical conditions influencing the crystallization, proving that the chemical constituents in the molten magma do not exist, wholly at least, in definite or fixed combinations or molecules corresponding to distinct mineral molecules. Moreover, if the molecular character of a molten magma shortly before it solidifies is not fixed, but is flexible, its molecular character at an earlier period, when differentiation may take place is undoubtedly flexible or unstable, and probably to a greater degree. This is indicated by the variability in the composition of minerals of the same group, such as pyroxenes, feldspars, etc., in rocks genetically related, and assumed to have been derived by differentiation from a common parent magma. Thus in genetically related rocks the feldspars may range from those high in potash to those high in sodium and to others low in alkali metals and high in calcium; pyroxenes may range from those rich in calcium and magnesium, with little iron and aluminium, to others richer in the latter elements and to those rich in sodium and iron. Several members of either of these mineral series or groups may occur together in one rock, and may occur in varying proportions in different rocks.

The facts known regarding the mineral composition of genetically related rocks, to which the theory of differentiation has been made to correspond, are that the proportions of the component minerals, as well as their chemical compositions vary not only with different bodies of rocks, but not infrequently with one rock-body. Furthermore, this variation is in many cases gradual, with known transitions, while in other instances differences of composition are marked, and transitional forms have not yet been found. Consequently from the theory of differentiation

[1] ROTH, J., Gesteinsanalysen in tabellarischer Übersicht, etc., Berlin, 1861, p. 21.

IDDINGS, J. P., Bull. Phil. Soc. Washington, 1892, Vol. II, p. 217. Also 12th Ann. Rep. U. S. Geol. Survey, Washington, 1892, p. 659.

LINDGREN, W., A Sodalite-Syenite and other Rocks from Montana, Am. Jour. Sci., Vol. XLV, 1893, p. 297.

rocks with variable proportions of the mineral constituents are to be expected to be the rule rather than the exception And when all igneous rocks are taken into consideration all possible combinations of mineral proportions may be anticipated.

The chemical relations of series of rocks genetically connected.— The chemical characters of genetic series of rocks has been considered their most distinguishing and essential characteristic— the one quality that established their consanguinity.[1] It might be thought then that such a feature could be employed as a means of classifying igneous rocks in groups corresponding to genetic series. Careful consideration of the actual nature of this chemical character will lead to the opposite conclusion.

Certain genetic groups of rocks are distinguished by relatively high alkalis, in one instance largely potash, in another largely soda. Other genetic groups are characterized by relatively low alkalis. But even in these series not every rock contains the same high or low alkali ratio as the preponderating varieties. In fact there are often members of the series which are chemically quite different from the greater number of rocks belonging to the series. In some genetic series it is the ratio between the potash and soda that is characteristic, the total alkalis being large in some rocks of the series and low in others. But here again the ratio is never constant, and the variation may be quite large.[2] In no one genetic series yet described has any single chemical character been found to be persistent throughout the series. Nevertheless the transitions between the rocks of the series are sufficiently pronounced to leave no reasonable doubt that the rocks in question have been derived from

[1] ROSENBUSCH, H., Ueber die chemischen Beziehungen der Eruptivgesteine, Min. u. petr. Mitth., Vienna 1889, Vol. II, pp. 144–178.

BRÖGGER, W. C., Die Mineralien der Syenitpegmatitgänge der Südnorwegischen augit- und nephelinsyenite, Zeitscht. für Kryst. u. Min., Leipzig, 1890, Vol. XVI.

IDDINGS, J. P., Origin of Igneous Rocks, Bull. Phil. Soc. Washington, 1892, Vol. XII, p. 135.

[2] BRÖGGER, W. C., Die Eruptivgesteine des Kristianiagebietes. I. Die Gesteine der Grorudit-Tinguait-Serie, Christiania, 1894, 165.

WEED, W. H. and PIRSSON, L. V., Geology of Castle Mountain Mining District, Montana, Bull. U. S. Geol. Survey, No. 139, 1896, p. 137.

some parent magma by some process of chemico-physical separation or differentiation.

Besides genetic series that are chemically quite distinct from one another there are others much less so, and others that resemble one another closely. Petrographical provinces are in some cases strongly contrasted chemically. But in certain regions there appears to be a gradual shifting in chemical composition of the rocks from one locality to another. This is well illustrated in the region embracing the Yellowstone National Park, the Crazy Mountains, Castle Mountain, Little Belt Mountains, Highwood, and Bearpaw Mountains in Montana.[1] The series of rocks at each of the localities named becomes relatively richer in alkalis from the south northward, potash assuming a very prominent rôle. The analyses from these localities to the number of 175 are compared with one another in Diagram 5, which shows the gradual shifting of the alkali-silica ratios.

In general a more or less gradual shifting of chemical characters with increase in alkalis obtains for genetic series of rocks from the Great Basin in Nevada, Idaho, and Utah eastward across the Rocky Mountains to the Black Hills, S. D., Leucite Hills, Wyo., Cripple Creek, Colo., into Arkansas and southward into the Transpecos region of Texas. Throughout this vast region there are innumerable genetic series of igneous rocks. The series from somewhat remote parts of the region are chemically quite clearly distinguished, but series from intermediate localities grade into one another so that there are in reality series of series. The term series in the sense here used applies to all igneous rocks of one petrographical province that belong to one period of volcanic activity, which may be of very great

[1] IDDINGS, J. P., The Eruptive Rocks of Electric Park and Sepulchre Mountain, Yellowstone National Park, 12th Ann. Rep. U. S. Geol. Survey, 1892, pp. 569–664. Origin of Igneous Rock, loc. cit. Absarokite-Shoshonite-Banakite-Series, JOUR. GEOL., Vol. III, Chicago, 1895, p. 935.

WEED, W. H. and PIRSSON, L. V., Geology of the Castle Mountain Mining District, Montana, loc. cit. Highwood Mountains of Montana, Bull. Geol. Soc. Am., Vol. VI, Rochester, 1895, pp. 389–422. The Bearpaw Mountains of Montana, Am. Jour. Sci., Vol. I, 1896, pp. 283, 351; Vol. II, pp. 136–188. Also Bull. U. S. Geol. Survey No. 148, Washington, 1897, pp. 117–136, 142–157.

duration, embracing a whole geologic period, as, for example, the Tertiary. It may include a number of lesser series of eruptions localized within the province, as at centers of eruptions such as volcanoes; and may be highly complex, having many branchings. In some series the range of chemical variations is comparatively small, in others it is comparatively great. Examples of these appear in the rocks of the Yellowstone Park and in those of the Christiania region, whose analyses have been plotted in Diagram 6; the red spots representing those of the Christiania region.

If more limited genetic series are compared it is found that in one case the chemical variation is chiefly in the line of silica, from much to little, accompanied by abundance of feldspar molecules for the higher silica, and abundance of ferromagnesian molecules for lower silica. While in another case the chemical variation affects the silica but slightly, and shows itself in the relative abundance of alkalis and alumina on the one hand, and of ferromagnesian molecules on the other.[1] The definition of a genetic group or family of rocks, as expressed chemically, must, therefore, be very flexible and indefinite.

The natural consequence of the variability of composition among rocks of one genetic series, and of the existence of genetic series closely similar to one another chemically, is the close resemblance of some rocks of one series to certain rocks of other series. And since the differences in most cases consist in the relative proportions of the same chemical elements, it follows that some rocks of one genetic series are quite as much like certain rocks of another series as these are like other rocks of the same series. Hence, a chemical definition broad enough to cover several closely similar rocks of one genetic series may apply equally well to similar members of another genetic series, and it cannot be framed so as to exclude them. In other words, it follows from the very nature of a chemico-physical differentiation of rock magmas that some rocks belong-

[1] IDDINGS, J. P., Absarokite-Shoshonite-Banakite Series, JOUR. GEOL., Vol. III, Chicago, 1895, p. 935.

ing to different genetic series, or to different petrographical provinces, may be chemically alike.

The same is true with regard to the mineralogical characteristics of rocks. Since these are primarily dependent on the chemical composition of the magma of each rock, and also on the physical conditions attending its solidification, it follows that the minerals composing certain members of any genetic series of rocks must be like the minerals in some members of other genetic series. Definitions based on the character and proportions of these minerals must apply equally well to members of several genetic rock series.

Moreover, the texture, granularity, and physical aspect of rocks depend on both the composition of the magma and the physical conditions under which solidification took place. The latter are independent of geographical position; that is, are not localized, but are universal, and cannot be peculiar to any petrographical province. They depend on the environment of the magma in each instance, and magmas in different provinces may have existed amid similar environment and have been exposed to almost identical physical conditions.

The most distinctive features of igneous rocks, then, their chemical and mineral composition and texture, cannot serve as means of discrimination of rocks of all genetic series, consequently a group or class of rocks which may be of essentially the same natures as regards these essential qualities may embrace rocks belonging to different genetic series. It follows from this that the classing of all known igneous rocks into groups that shall have essentially the same chemical and mineral composition and texture, and which may be designated by definitions expressed in terms of these qualities, must disregard the genetic relations among the rocks of different classes.

The nature of a rock-body or geological unit.—In the foregoing discussion the term rock has been used as though applied to a mass having in each case some definite composition and texture. But it is well known that in large masses this is not always the case. In some masses the texture varies in different parts of

the whole; in others the chemical and mineral composition varies.[1] These variations may be slight and within what may be considered the limits of variation for a given class of rocks, or they may be so great as to exceed these limits, and different parts of one continuous rock-mass may have characters belonging to different classes of rocks in the usual sense. The same variations and relations exist between different parts of some rock-masses as those just mentioned as existing between some rock members of various genetic series of rocks, and for exactly the same reason. Hence, definitions of rocks based on the essential, material characters—composition and texture—cannot be made so as to discriminate always between various rock-masses.

Rock-masses of this kind are geological bodies, in that they form integral parts of the crust of the earth, such as lava streams or sheets, dikes, laccoliths, stocks, etc. Rock-masses or rock-bodies, in distinction from rocks as considered in this discussion, can not be grouped in classes on the same basis as those on which the rocks can. They may be classified according to their form or dimensions, or their mode of occurrence, or according to some general idea of composition, as homogeneity and heterogeneity.

A knowledge of the characteristics of all rock-bodies as such is necessary to a proper understanding of the mode of occurrence of igneous rocks, and is essential to any comprehensive treatment of the science of petrology.

The nature of genetic series of rocks.—The character of series of rocks that occur associated in any region so as to be considered as genetically related, differ widely in different cases. Aside from the fact that all those in one region may have solidified within the crust of the earth, while those in another region may have reached the earth's surface and have consolidated at the surface and also within the crust, there are the subsequent geological events that have transpired in each case since solidification whereby the present exposure of the rocks has been

[1] IDDINGS, J. P., Genetic Relationships among Igneous Rocks, JOUR. GEOL., Vol. I, Chicago, 1893, pp. 833–844.

brought about. This may reveal parts of all the rock-bodies originally present, or much more probably only a certain number of all once in existence, some having been entirely removed or still remaining covered. The rocks exposed in any region seldom represent the whole series of varieties that actually exist or did exist in the region. Consequently some series or associations represent comparatively few varieties of rocks, and these often quite different from one another, as when only basalt, rhyolite, and one or two varieties of andesite occur in a region, whereas other series exhibit many varieties and frequent transitions from one to another as in the dissected volcanoes in the Yellowstone Park region. Again, it is found that the range of rock varieties in some regions is limited, and in others is very wide, indicating less differentiation of the parent magma in one case than in another.

A knowledge of these associations in various regions leads to a comprehension of the laws governing the production of varieties of igneous rocks, both their probable differentiation from a parent magma, and something of the mechanism of their eruption, consequently its importance in a treatise on petrology cannot be overestimated. The consideration of these relationships is absolutely essential to a right conception of the true nature of igneous rocks.

Classification of igneous rocks and the didactic treatment of petrology.—It is hoped that the foregoing discussion has made it apparent that a systematic classification of all kinds of igneous rocks cannot be put on the same basis as a philosophical treatment of the subject-matter of petrology, which takes cognizance not only of the material character of rocks, but also of the laws governing their production, eruption, mode of occurrence, and solidification, as well as their subsequent alteration.

The object of a classification of rocks is clearly the bringing together of those that have like characters in order that they may receive a common name, and that their descriptions may be systematically arranged for convenient reference. The use of names common to all similar rocks instead of individual names, such as are given to men, is also solely for convenience; it being

considered more useful to emphasize the characters common to the rocks bearing a common name than those which might distinguish them as individuals. Moreover, it must be admitted that there is need of a systematic arrangement of descriptions of rocks, and that the descriptions of all similar rocks should be found together.

With the need of systematic classification of descriptions of rocks is an equal necessity for a systematic nomenclature. The present nomenclature is an inheritance of the most fortuitous creations of the earliest investigators, whose knowledge was of necessity often imperfect or faulty, and of recent petrographers, whose suggestions of names have been based on no uniform system. The earlier names have undergone such changes of definition as in more than one case to shift them entirely from their original application. Terms derived from geographical localities, from physical characters, or from mineral components, have been used indiscriminately. Rocks differing from one another but slightly have in some cases received totally different names, in other cases names alike except for qualifying prefixes. The time has nearly arrived for a complete reformation of petrographic nomenclature. The need is urgent but the condition of our knowledge at present is scarcely such as to warrant the immediate attempt to create a systematic nomenclature. When it is devised it should not only be sufficient for present needs, but should be capable of further development along with the growth of our knowledge of the rocks themselves.

The object of a treatise on igneous rocks should be to convey an idea of the origin and geological history of such rocks, their intricate relationships with one another, and their material characteristics. To accomplish this, the known facts may be presented in a number of ways, and the subject may be approached from different directions. Different methods of procedure may commend themselves to different writers, and may be followed with equal success. But there should be one systematic nomenclature based upon some universally accepted classification. The exact nature of this classification has yet to be determined.

JOSEPH P. IDDINGS.

EDITORIAL.

AMONG the various organizations working for the promotion of science, the state academies of science have recently become prominent, particularly in the middle west. The Ohio, Indiana, Wisconsin, Minnesota, Iowa, Nebraska, and Kansas academies are doing an important and highly valuable work. In most cases their meetings are held at some time during the winter holidays, and they bring together a large proportion of the influential men of science of their respective states. Our country is a large one and to many a scientific worker the pilgrimage eastward to the winter meeting of his special society is something only to be undertaken after careful consideration of ways and means. To such a one the state academy is a real boon, and in any event the coming together of men of scattered but related fields of work is perhaps as productive of good as the meeting of specialists alone.

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THE state academy is, however, making a peculiar place for itself aside from serving as a meeting place for various scientific workers. It is rapidly becoming a molder of public opinion on the numerous semi-public scientific questions which are constantly springing up. It is the adviser of the legislature in matters of scientific work and its potency in that direction has been instanced in the part taken by the Wisconsin and Iowa academies in securing the legislation necessary for geological and natural history surveys. In several of the states this semi-public position of the academy has been recognized, and the state has undertaken to publish the proceedings.

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IN the recent meetings of the state academies the geologists have as usual taken an active part. The Minnesota meeting,

being the twenty-fifth anniversary, was celebrated by a very attractive programme. Papers were read by Winchell, Grant, Sardeson, Berkey, and others upon various geological problems. The Iowa programme included papers by Todd, Calvin, Keyes, Udden, Sardeson, Bain, Leverett, and others and was particularly interesting to students of the drift. The Wisconsin programme embraced papers by Van Hise, Collie, Hobbs, Lurton, Slichter, with a report of progress of the Geological and Natural History Survey by Birge and Marsh. The Indiana programme was also a strong one, and the Nebraska meeting, held some time earlier, was well attended. The publication of the proceedings of these meetings will be awaited with interest. H. F. B.

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MESSRS. SPRING and ROWLAND have recently communicated to the Belgium Academy a series of observations made upon the amount of carbonic acid contained in the atmosphere during the year. They give the result of 266 determinations made in the city of Liege, Belgium, on one side of which there is an industrial and on the other an agricultural district. The average amount of carbonic acid contained in ten thousand parts of air was 5.1258 parts by weight and 3.3526 parts by volume. These gentlemen remark that this is more than the amount contained in the air of Paris, which is 4.831 parts by weight and 3.168 by volume. The large amount at Liege is owing not only to the large iron works there but also to the fact that the city is surrounded by coal mines. To this the authors attribute the greater heat of the city as it is well known that a small amount of carbonic acid in the air causes the absorption and prevents the radiation of heat. They also attribute the cold weather of May to the diminution of the carbonic acid caused by its consumption by the exceptionally vigorous growth of leaves at that season. Their observations show that a fall of snow will increase the amount to 3.761 by volume and that in cloudy weather the amount was 3.571 parts and that there was always a larger amount in winter than in summer. They also found that the amount was diminished by high winds but increased

with a high barometer. (Egleston Thomas, *Trans. Am. Soc. Civil Engineers*, Vol. XV, p. 650, New York, 1886.) H. F. B.

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THE attendance at the Montreal meeting of the Geological Society of America was small, but the session was both pleasant and profitable. The hospitality of the people of Montreal, always cordial, was notable for its warm-heartedness. The interest and importance of the papers compared very favorably with those of the preceding sessions, and in several notable instances possessed peculiar interest. The presidential address of Dr. Orton was an admirable exposition of the theoretical aspects of petroleum and was made attractive not less by the charm of its manner than by the judiciousness of its matter. The pleistocene papers as usual led in number, but the preponderance was but slight. The petrological papers followed them closely in number and perhaps surpassed them in fullness and in the labor of preparation. Two of them were especially notable for their careful elaboration. It was gratifying to observe a relative increase in palæontological papers. It has been a source of deep regret to many American geologists that palæontologists have in recent years so largely drifted in the direction of phylogeny (important as that is) and that the study of faunas and floras as such and as factors in the history of the earth has not found larger expression in the papers of the Geological Society. The evolution and migration of faunas and floras is comparable if not superior in importance and interest to the evolution of species and families, and merits an ample share of palæontological effort. Papers upon regional geology, which have always constituted a notable proportion of the programme, held a fair place at the Montreal meeting. The dynamical papers were few, but the peculiar interest which attached to the experiments of Dr. Adams on the flow of rocks under pressure made full atonement for the scantiness of their numbers. The important paper of Professor Van Hise on "Shortening of the Outer Part of the Earth" was read by title only. Physiographical papers which have sometimes occupied a prominent

place on the programme found notable expression in but a single presentation.

The following is a list of the titles of the papers offered. Abstracts of a portion of these appear in this number of the JOURNAL and others will follow:

"Notes on the Sands and Clays of the Ottawa Basin." By R. W. ELLS.

"Topography and Glacial Deposits of the Mohawk Valley." By ALBERT P. BRIGHAM.

"Topography and History of Jamesville Lake, N. Y." By EDMUND C. QUEREAU.

"Location and Form of a Drumlin at Barre Falls, Mass." (By title.) WILLIAM H. NILES.

"Drift Phenomena of the Puget Sound Basin." (By title.) By BAILEY WILLIS.

"Niagara Gorge and St. David's Channel." By WARREN UPHAM.

"Notes on the Moraines of the Georgian Bay Lobe of the Ice-Sheet." By FRANK B. TAYLOR.

"Notes on the Geology of Montreal and Vicinity." By F. D. ADAMS.

"Notes on the Geology of the Rocky Mountains of Montana." By WALTER H. WEED.

"Marine Cretaceous Formations in Deep Wells in Southeastern Virginia." By N. H. DARTON.

"The Cretaceous Series of the West Coast of Greenland." By CHARLES SCHUCHERT and DAVID WHITE.

"Note on Lepidophloios Cliftonensis." By SIR WILLIAM DAWSON.

"Omphalophloios, a new Lepidodendroid type." By DAVID WHITE.

"The Mastodon in Western Ontario." By H. M. AMI.

"Mastodon and Mammoth Remains Found near Hudson Bay." By ROBERT BELL.

"Fossil-like Forms in Sault Ste. Marie Sandstone." By ROBERT BELL.

"Weathering of Alnoite in Manheim, N. Y." By C. H. SMYTH, JR.

"Syenite-Porphyry Dikes in the Adirondack Region. By HENRY P. CUSHING.

"Nodular Granite from Pine Lake, Ontario." By FRANK D. ADAMS.

"Chemical Composition of the Granite from Pine Lake, Ontario." By NEVIL N. EVANS.

"Clastic Huronian Rocks of Western Ontario, and the Relation of Huronian to Laurentian." By A. P. COLEMAN.

"The Classification of Igneous Rocks." By JOSEPH P. IDDINGS.

"The Geological *versus* the Petrographical Classification of Igneous Rocks." By WHITMAN CROSS.

"Geological Probabilities as to Petroleum." (President's address.) By EDWARD ORTON.

"On the Occurrence of Corundum in North Hastings, Ont." By A. E. BARLOW.

"The Harvard Geographical Models." W. M. DAVIS.

"Experiments on the Flow of Rocks, now being conducted at McGill University." By FRANK D. ADAMS and JOHN T. NICOLSON.

"Estimates and Causes of the Shortening of the Outer Part of the Earth." By C. R. VAN HISE. (By title.)

"New Geothermal Data from South Dakota." By N. H. DARTON.

"Concentric Weathering in Sedimentary Rocks." By T. C. HOPKINS.

"Note on an Area of Compressed Structure in Western Indiana." By GEORGE H. ASHLEY.

T. C. C.

Authors' Abstracts.

PAPERS READ AT THE MONTREAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA.

Sands and Clays of the Ottawa Basin. By R. W. Ells.

The paper describes the leading physical features of the Ottawa River basin, which comprises about 130,000 square miles, and which includes numerous large streams, both from the north and south. The elevations of the height of land on the north, which divides the Ottawa waters from those which flow into James Bay, are given as ranging from 900 feet at Grand Lake, one of the large expansions in the upper part of the Ottawa River, to about 1100 feet near the source of the stream. Further east at the head of the St. Maurice, the elevation is somewhat greater, probably between 1300 and 1400 feet. The height of the divide to the north of Lake Temiscaming is given as 923 feet, while the elevation of Lake Temagami, which empties from the south into Lake Huron and from the northeast into the Ottawa, is 967 feet above sea. The height of land along the southern rim of the basin ranges from 645 feet at Lake Nipissing to about 1400 feet at the head waters of the Petewawa and Madawaska rivers, decreasing to 417 feet at the head of the Rideau.

Over all this area to the height of land, apparently continuous deposits of a blue clay, similar in character to the recognized marine clays of the lower Ottawa and St. Lawrence basins, can be seen. These have in places a thickness of over 100 feet, and they are overlaid over a great portion of the basin by sands, similar in character to the well-known Saxicava sands which contain marine fossils further east. In the eastern part of this area well defined deposits of these clays and sands holding marine shells, are found at elevations of nearly or quite 600 feet above sea level, while shore lines and old beaches, also of marine origin, are to be seen along the north side of the St. Lawrence, as well as along the lower Ottawa, which range in elevation from 600 to at least 1000 feet above present sea level. The bones of a whale

have been obtained from a large kame-like ridge near Smith's Falls at a height above sea of 440 feet, the skeleton being reached in the excavation at a point 50 feet from the outer zone of the ridge. This elevation is nearly 200 feet above the present level of Lake Ontario. The indications of submergence, as seen along the sides of the Montreal mountain, are clear at elevations from 220 to 750 feet or nearly to the summit. Similar high level beaches are found along the slopes of the mountain ranges in eastern Quebec to a height of nearly, or in places quite 1000 feet, so that it may be considered as fairly well established by the latest evidence that this portion of Canada was submerged, subsequent to the glacial period, to a depth of at least 1000 to 1200 feet. All the high level beaches in the St. Lawrence and Ottawa valleys front directly to the open estuary of the St. Lawrence River, and there were, in so far as can now be seen, no barriers to interrupt the inland spread of the sea between that river and the upper great lakes. The submergence mentioned would carry these waters over the height of land in nearly every part of the Ottawa basin and support the view now put forward that the clays which are found on most of the portages at the highest levels are marine. It is probable also on this theory that the Erie clays, which are very similar in character to those of the lower Ottawa, and unconformable to the overlying series, are the true equivalents of the Leda clays of the eastern area, though this point requires further detailed examination before the exact relations of the fresh water deposits of this part of Canada to the underlying clays can be completely established.

Note on an Area of Compressed Structure in Western Indiana. By GEO. H. ASHLEY.

As is well-known, the rocks of Illinois, most of Indiana, and part of Kentucky form a basin with gently dipping slopes, and where local evidences of stress are observed they usually indicate tension. Thus the faults are commonly tension or normal faults, and the joints are perpendicular and open. Recently several local areas of disturbance have been observed and this note is intended to call attention to one of these. In this case the evidence of considerable tangential pressure is seen in (1) overthrust or pressure faults, (2) coal beds compressed laterally until they become several times their original thickness; (3) in place of perpendicular open joints, confined to the coal

and with faces even but not polished or showing any indication of rubbing, such as are common in the region as a whole, are found regular oblique joints, cutting the roof and floor as well as the coal, and having their faces much slickened. These joints are evidently shearing planes, and show signs of incipient movement, or in some cases, as in one of the figures given, they become fault planes allowing the lower of two coal beds twenty feet apart to slide an unknown distance up over the upper bed. The main system of joints dip to the north, a second set sometimes developed dip to the south. The pressure acted with the general strike of the rocks. The area described covers a few square miles southwest of Asherville, Clay county, Ind. The structure has been disclosed by the operations of mining.

Syenite-porphyry Dikes in the Adirondacks. By H. P. CUSHING.

Interesting dikes of pre-Potsdam age have been recently found in the Adirondacks which constitute the complementary rocks to the diabases of the region. Basal conglomerates of the Potsdam contain pebbles derived from them. On the other hand, together with the diabases, they comprise the only unmetamorphosed pre-Potsdam rocks known in the district.

These dike rocks are made up of feldspar, quartz, and biotite, with or without hornblende, and with accessory iron ores, apatite, augite, titanite. Both orthoclase and albite feldspar are present, commonly intergrown as microperthite. The rock is porphyritic, both feldspar and biotite occurring in two generations, the latter only sparingly. The feldspar largely predominates over all other minerals, constituting from 60 to 80 per cent. of the rock. The ground mass structure is trachytic or orthophyric.

Chemically the rocks are characterized by high alkali and low lime-magnesia percentage, and rather low ratio of alumina to silica. They belong to the alkali-syenite group of Rosenbusch. Their bunched distribution and mineralogic similarity indicate that they were products of a common magma, and if that be so they afford an interesting case of magmatic differentiation as they range from 69 to 52 per cent. of silica. With decreasing silica the lime, magnesia and alkali percentages rise, the latter retain their preponderance.

The greater number of the dike rocks would be classed as syenite-porphyries, nordmarkite, and pulaskite types. The more acidic repre-

sentatives belong properly with the alkali-granites. The most basic rocks represent an undescribed type, so far as the writer is aware, being very basic mica-syenite-porphyries.

Together with the diabases these rocks form an eruptive assemblage quite similar to that which characterizes Keweenawan time in the upper lake region, nor, since there is in each case the same relationship to a younger unconformable sandstone of upper Cambrian age, and to an older mass of gabbroic intrusives, can they depart widely from them in age.

Leaving out of the question the older gneisses of somewhat doubtful origin, there were three distinct periods of igneous activity in the Adirondack region. The earliest gave rise to gabbros and granites, the next to diabases and syenite-porphyries, the last to bostonites and various basic rocks (camptonites, monchiquites, etc.). Analyses show an astonishing agreement between the acidic rocks of each period on the one hand and the basic rocks on the other. Though a long time interval elapsed between each, magmatic relationship seems not unlikely.

Accumulating evidence seems to the writer to indicate the possibility that three similar periods were characteristic of the entire shore line of the Canadian and Appalachian protaxes, and that such possibility should be added to the working hypotheses of all workers in that field.

(Other Abstracts, Reviews, and Publications deferred to next number.)

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BRAZILIAN EVIDENCE ON THE GENESIS OF THE DIAMOND.

THE extensive working of the "dry diggings" of South Africa has thrown a light on the original associates and probable mode of origin of the diamond, which it would be vain to look for in the ordinary type of diamond fields as known in other parts of the world, since all of these, with rare and imperfectly known exceptions, correspond almost exactly with the river washings of the Cape district. The group of mines about Kimberley have shown beyond a doubt that here at least the association of the diamond is with an eruptive rock of ultra basic composition, and, although opinions differ as to the exact mode of origin, all authorities seem to agree on the main fact that in some way this association is a genetic one. To one familiar with the Brazilian diamond fields this conclusion seems a startling one and utterly inapplicable to them. The evidence in its favor, if any exists, is either concealed and has been overlooked, or, as at first sight seems most probable, a totally different association is presented, necessitating the hypothesis of the formation of the mineral under a far wider range of conditions than has been admitted by the students of the Kimberley occurrence. In the present paper it is proposed to discuss the observations, in great part unpublished, that have thus far been made in Brazil bearing upon the question of the genesis of the diamond, with a view of seeing in how far they are in accord, or disaccord, with the much more complete observations in the South African mines.

With two exceptions, which will be more fully discussed below, all the known Brazilian diamond washings are in material — sand and gravel — which has clearly been transported from its place of origin and equally clearly contains the débris of a greater or less variety of rock types, some one or more of which may reasonably be presumed to have a genetic relation to the diamond. As the latter, however, is almost invariably found free in such deposits, or attached to the other elements by a cement, usually limonite, which is visibly of secondary origin, such deposits throw little light on the history of the gem. For the most part these deposits are of quite recent origin, having evidently been formed by the action of the present drainage agencies. In a few cases the gravel has been attributed[1] to the disintegration of conglomerates of various ages, which in one case is presumed to be very great. The age of the gem is thus carried back to a more or less remote geological period, but no other essential addition is made to its history. The concentrates of the rarer and heavier elements of these gravels obtained by the miners in their operations contain many rare and interesting minerals which have attracted the attention of mineralogists, but, thus far, the hopes that have been entertained of tracing the diamond to its original home by means of these satellites, have proved illusive, since none of them have proven to be sufficiently constant to give more than merely presumptive evidence. The few cases that have been reported of diamonds included in other minerals, as iron ores and rarely quartz and anatase, refer to minerals that are known to be readily formed by secondary action, and thus are not necessarily contemporaneous with their inclusions.[2]

The associates of the diamond in these gravels are naturally fragments of all the rocks capable of resisting decay and the

[1] DERBY: Am. Jour. of Sci., 1882, XXIV, p. 34.

[2] The specimen described by Eschwege, who attributed great importance to it (Geognostisches Gemälde, p. 430; Beiträge zur Gebirgskunde Brasiliens, pp. 213 and 341), and which is now in the Heuland collection in the British Museum, is apparently a cleverly executed fraud. The limonite and scorodite of the drusy cavity in which the diamond rests present the peculiar and very characteristic aspect of these minerals

wear of transportation that have contributed to the deposit, together with the isolated minerals derived from the breaking down of these rocks and of such others as have entirely disappeared as rock-masses and are now only represented by the more resistant of their constituents, which have been more or less completely assorted according to their resistance to disintegration and to wear, to their specific gravity and to the size of grain. These isolated minerals, the *formation* of the miners, who attach great importance to them, can in some cases, as of zircon, monazite, xenotime, etc., be referred with tolerable certainty to original eruptive rocks, though they may, and in many cases doubtless have, passed through others before reaching their present place in the gravels; others, as staurolite, disthene, etc., can with equal certainty be referred to metamorphosed clastics, but by far the greater part, as quartz, the iron and titanium oxides, tourmaline, garnet, and many others might be from either eruptives or metamorphosed clastics, or from both. The minerals which can with more or less probability be attributed to eruptive rocks, are not so predominant or so constant in their occurrence that any particular significance can be attached to them. Their evidence, so far as it goes, points rather to the acid eruptives, as granites, etc., than to the ultra basic types of the Kimberley district.

In only one Brazilian mine, so far as known, are basic eruptives a characteristic feature, and in this the conditions are such that the association seems to be accidental rather than genetic. This is the Agua Suja (dirty water) mine in the Bagagem district of western Minas Geraes, which has been excellently studied by Messrs. Gonzaga de Campos, Hussak, and Calogeras,[1] though

from the gold mine of Antonio Pereira, near Ouro Preto, which is the only known Brazilian locality of scorodite, but is not known as a diamond locality. The specimen is reported to come from the Abaieté district to the west of the São Francisco, but no other specimens of scorodite, or of limonite of this character, are known from that region, where, moreover, only gravel deposits had been worked, whereas the specimen in question is evidently from a mine, and not from a deposit of transported material.

[1] GONZAGA DE CAMPOS: Jazidas Diamantiferas de Agua Suja, Rio de Janeiro,

much is yet to be learned regarding this unique deposit. The region is characterized by inclined strata of micaceous schists in part staurolitic, which are regarded as metamorphosed clastics, with intercalations of amphibolites, which are almost certainly metamorphosed eruptives. This schist series is cut by dikes of granite which, so far as observed, are characterized by muscovite either alone or in association with biotite, and which are generally tourmaliniferous. Quartz veins which frequently carry a little mica are also common. Upon this group of schists and granite rest horizontal beds of soft sandstones with intercalated layers, or sills, of trap—augite-porphyrite or melaphyre—which are presumably of Triassic age. In the same region, although not definitely known in the immediate vicinity of the mine, there is another obscure eruptive group which has furnished material characterized by grains of pyroxine, perofskite, and magnetite, to beds of clay and impure limestone that overlie the sandstone and trap, and, in places, present something of the aspect of ash-beds or volcanic breccias. This group, though very imperfectly known, is certainly distinct from the traps, and its probable relations will be discussed below.

The diamond-bearing bed of Agua Suja is a thoroughly decomposed conglomerate, or breccia, in which both matrix and the included pebbles are transformed into clay. The original angular outline of the pebbles (or rather bowlders, as they are often of considerable size), can, however, be recognized, as also in many cases, the type of rock to which they belonged. The various types of the schists and granites upon which the diamantiferous bed rests in part (in part also on sandstone and trap) are recognizable, as well as masses of the sedimentary and later eruptive series. Fragments of opal, which may be of secondary origin, constitute a peculiar feature when this mine is compared with others of the same region (Bagagem) or of the other diamantiferous regions of Brazil. Still more peculiar and

1891. E. HUSSAK: In the above cited pamphlet and in Relatorio da Commissão Exploradora do Planalto, Rio de Janeiro, 1894. J. P. CALOGERAS: Revue Universalle des Mines, XXIX, 1895.

characteristic is the presence in great abundance of magnetite and of a magnetite rock, which Dr. Hussak has succeeded in tracing to a special magnetite-perofskite type found by him near Catalão, in the state of Govaz.[1]

This last element of the diamantiferous bed cannot be referred to any of the known rocks of the region, but it points in the same direction as the above mentioned eruptive elements of the limestone and clay beds that are known to occur in the region and that may be presumed to extend to the immediate vicinity of Agua Suja. These elements, pyroxene, perofskite and magnetite, suggest a type of basic eruptive passing into an iron ore such as has actually been met with in the Jacupiranga district of the state of São Paulo in genetic relations with various nepheline-bearing rocks, the whole constituting a typical volcanic series.[2] As a somewhat similar volcanic center is known at Caldas[3] at no great distance from the Agua Suja region, there is a reasonable probability that another one may exist in the immediate vicinity, and that it may have furnished the problematic material of the diamantiferous bed. This last is not clearly referable to the present drainage conditions of the country and is very likely to prove to be an ancient conglomerate, or breccia, possibly in relation with the eruptive manifestation that is presumed to have contributed to its elements.

The Agua Suja occurrence thus offers a certain number of analogies with those of the Kimberley district which are entirely lacking in the other Brazilian localities, so far as they are known. It is especially to be noted that the absence of these analogies is as conspicuous at the nearest locality, Bagagem, only about twenty miles distant in the same river basin, as at any other. The country rock both at Kimberley and Agua Suja is horizontal, of approximately the same age (late palæozoic or early secondary) and with intercalated sills of trap of very similar character and composition, but which in both cases has no

[1] Neues Jahrbuch, 1894, II, p. 297.

[2] DERBY: Am. Jour. of Sci., XLI, 1891, p. 311.

[3] DERBY: Quart. Jour. of the Geol. Soc., 1887, p. 457.

apparent relation with the occurrence of the diamond; the deposit is conglomeratic, or brecciated, and in both cases the most characteristic elements of the conglomerate represent rocks of an ultra basic type, and in both the diamond is presumed to be an element of the cement rather than of the included pebbles; perofskite and garnet (pyrope) are characteristic accessories (garnets though frequent in most Brazilian sands and gravels are exceptionally rare in those of the diamond washings; those of Agua Suja present the rare cubic habit); the diamonds *seem* to be distributed with a considerable degree of uniformity throughout the mass.

With these analogies are, however, associated differences that are, in appearance at least, of equal if not greater importance. The Agua Suja deposit is a bed, not a volcanic neck; in it clastic elements, of a much more varied character than those of Kimberley greatly predominate over those of eruptive origin, which also are more varied in character; the cement is apparently clastic rather than eruptive; the eruptive elements, exclusive of the trap, probably represent basic phases of the nepheline- or augite-syenite type of rocks and not the peridotitic, and there is as yet no direct evidence that they have anything to do with the diamond; the original matrix of the garnets is unknown and there is no evidence that their association with the diamond and with the basic eruptives is direct and not accidental. If, as is quite within the range of possibilities, eruptive necks of the Kimberley type should be discovered in the Agua Suja region, or contemporaneous (?) sedimentary deposits of the Agua Suja type in the Kimberley district, some of these differences would doubtless become analogies, but that of the *probable* original rock type would still remain and would require an extension of the views at present held regarding the type of eruptive rocks with which the diamond is associated. If, as some hold in regard to the Kimberley occurrence, the diamond is the product of meta morphic action on carbon-bearing rocks and not an element of the eruptive rock itself, this last difference would lose much of its importance. In this case, the Kimberley and Agua Suja

occurrences would fall into line as phases of the same phenomenon of contact metamorphism, and to this it may be added that the, at present, striking differences between the latter and the other known Brazilian occurrences would be reconcilable.

Before leaving the topic of African analogies it may be mentioned that in another Brazilian diamond region, that of the river Abaiete, a porphyritic peridotite (picrite-porphyry) with perofskite, quite similar to that of Kimberley as described by Lewis and others, has been found. Its known occurrence is, however, at some distance from the diamond washings and no relation between the two would ever have been thought of if it had not been for the Kimberley occurrence.

In the oldest and best known of the Brazilian diamond fields, that of Diamantina in Minas Geraes, there is an apparent relation, first noted by Eschwege in 1822 and confirmed by all subsequent writers, between the distribution of the diamond and that of the quartzose rock known as itacolumite. Eschwege who first described this rock[1] recognized a schistose and a massive type, the latter often presenting a conglomeratic appearance and, occasionally, an apparent lack of conformability with the former.[2] As, however, both types, and the schists associated with the schistose one, were considered as constituting a single division of the primitive group and as having a special, and non-clastic, mode of origin, the two were not separated and the question of the conglomeratic character was left by Eschwege as an unsolved problem. The predominance of the massive type of itacolumite in the Diamantina region was noted and from this a genetic relation between the rock and the diamond was inferred, an hypothesis which has become deeply rooted in mineralogical literature. About 1840, and after the publication of Eschwege's various works, diamonds were actually discovered and worked in this rock at Grão Mogol, some 100 miles, more or less, to the northward of Diamantina. The locality was

[1] Geognostisches Gemälde von Brasilien, und wahrscheinliches Muttergestein der Diamanten, Weimar, 1822.

[2] Beiträge zur Gebirgskunde Brasiliens, Berlin, 1832, pp. 210, 216.

visited and minutely described by Helmreichen[1] who confirmed Eschwege's views of the genetic relation of the diamond with itacolumite, although he confessed a doubt as to whether the rock, which had a conglomeratic aspect, might not be of clastic origin. Subtantially the same view was taken by Heusser and Claraz[2] who also visited the locality and who considered itacolumite as a quartzose phase of hornblende-schist and attributed the apparent pebbles of the diamond-bearing bed to concretionary action. In 1882, the present writer showed[3] that in the Diamantina region the massive itacolumite of Eschwege really constitutes an independent formation resting unconformably on the upturned edges of a lower series to which the schistose type belongs, and containing elements derived from it, the diamond being probably one of these derived elements. Several of the "dry diggings" of the vicinity of Diamantina were cited as being probably disintegrated masses of this ancient and metamorphosed conglomerate and the Grão Mogol deposit, which was not seen, was referred to as being presumably another example of the same kind. Professor Gorceix who afterward visited the Grão Mogol locality, and who for the Diamantina and other regions accepted my view of the dual character of itacolumite as originally described, agreed with Helmreichen and Heusser and Claraz in uniting the diamond-bearing bed with the lower schistose itacolumite, but, in opposition to their view, he considered the whole series as clastic.[4] The pebbles, or pebble-like bodies of the old writers, of the diamond-bearing bed were thought to be derived elements, while the mica, pyrite and martite of the same rock were considered as authigenic. The question as to which of these two groups of elements the diamond should be referred was, on theoretic grounds, decided in favor of the latter, a view that was rendered necessary by that

[1] Ueber das Geognostische Vorkommen der Diamanten und ihre Gewinnungsmethoden auf der Serra do Grão-Mogor. Vienna, 1846.

[2] Zeitschrift d. deutsch. geol. Gesellschaft, XI, 1859, p. 448; Petermann's Mitth., 1859, p. 447.

[3] Am. Jour. of Sci., 1882, XXIII, p. 97; XXIV, p. 34.

[4] Bulletin de la Societé Géologique de France, XII, 1884, p. 538.

of the unity of the formation, since elsewhere the diamond was considered to be authigenic under different conditions in a different rock referred to the same geological series.

The question of the unity of the section at Grão Mogol and of the clastic origin of at least the upper portion to which, according to all authorities, the diamond is confined, is an important one in this connection, since, if Gorceix's view is correct, it involves that of two widely different modes of genesis for the diamond in the same field. Not having seen the place, it is with considerable diffidence that I venture to contest the views of the eminent authorities who have.

The accompanying figure, reproduced from one of Helmreichen's sketches, gives what seems to me to be a more accurate

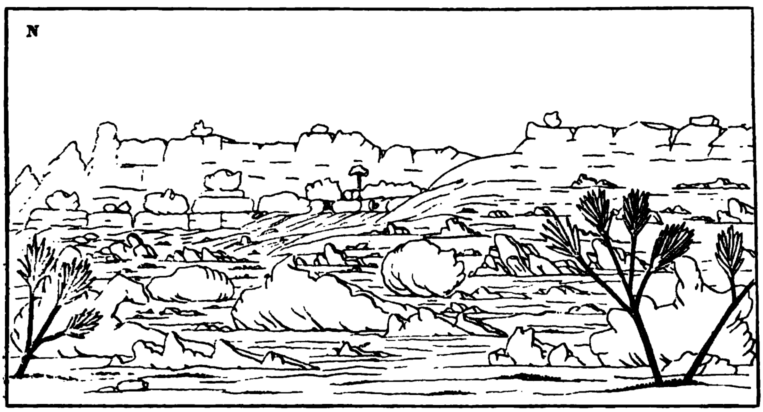


FIG. 1.—Left bank of Corrego dos Bois, near Grão Mogol showing diamond-bearing bed (*a*, *b*). After Helmreichen.

representation of the actual aspect of the exposure than the somewhat diagrammatic section given by Gorceix, and it has the further element of authenticity of representing, at the base of the diamond-bearing bed (*a*, *b*), an apparent unconformability that is not in accord with the theoretic views of the author of the sketch. Numerous cases of a break in the succession have, on close examination, been observed in the Diamantina district that are much less apparent in the topographical features than

the one presumed to be here represented. The two rocks a often found united in the same rock-mass in such an intima manner that, given the almost perfect identity in aspect a character, one is frequently inclined to doubt the evidence his senses even after unequivocal proofs of the existence of break have been detected. Similar cases of a complete blen ing of his massive and schistose types are graphically represent in other sketches given by Helmreichen which can best be int preted on the hypothesis of an unconformability. In the pr ent case, it seems to me that, admitting the accuracy of t sketch, the appearance of a break is so evident that befo rejecting it most geologists would require much stronger e dence than has yet been presented.

A recent examination of a specimen with an inclosed diamo in the collection of the National Museum at Rio de Janei shows that the Grão Mogol rock contains both authigenic a allothigenic elements to either of which groups, leaving out account considerations derived from other points, the diamo might with equal plausibility be referred. The predomina element quartz, which is presumably allothigenic, has by recryst lization, secondary enlargement, or other process, taken on t aspect of an authigenic element. The mica-like mineral (app rently a clintonite) and the iron minerals, pyrite and marti (magnetite?) are certainly authigenic. Allothigenic elemen are represented (leaving out of account the pebbles which a not well defined in the specimen in question) by distinctly roll zircons. Specimens of typical *schistose* itacolumite, which thou not from Grão Mogol may be taken as representing the suppos lower series of that place, present the same mixture of auth genic and allothigenic elements (the latter represented by w rolled zircons) and therefore the same evidence of clastic origi

As the case stands at present, the evidence from Grão Mog regarding the genesis of the diamond is inconclusive. The roc whether one or two series are represented, is a metamorphos clastic and no decisive evidence can be presented to place t diamond in the class of either the authigenic or allothigenic el

ments of this rock. If it belongs to the former class, two modes of genesis must be admitted in the same field in order to reconcile the occurrence with that at São João da Chapada ; if to the latter, the two occurrences can be explained on the hypothesis of a single mode of genesis, but, in case the series proves to be a single one, two periods of formation must be admitted.

For the question of genesis the most significant of the Brazilian localities is that of São João da Chapada near Diamantina

FIG. 2.— Diamond mine at São João de Chapada. The view is looking northward into the Barro mine, which runs into the Duro under the footbridge. The diamond-bearing layers dip into the bank at the right at an angle of about 50°. The open space in the foreground where the wash-house, concentration tanks (*canoas*), and heaps of diamond-bearing earth are located, represent the excavated portion of the left bank containing the upward prolongation of the diamantiferous layers. The wide trench near the pump-house at the left is apparently on the outcrop of one of the layers.

which has never been satisfactorily studied and described. The accompanying view, drawn from a photograph, which is also reproduced in Boutan's monograph on the Diamond in Fremy's *Enclyclopedie Chimique*, shows its character as a great gash resembling a railroad cutting across the crest of a high ridge that forms part of the divide between the waters of the Jequitinhonha and

the São Francisco. Two mines, the Barro (clay) and the Duro (hard), opened on opposite sides of the ridge have come together in the center (the footbridge in the middle ground of the view marks the division) so as to form a continuous cutting nearly 500^{m} long with about 40^{m} of maximum depth. The Barro mine drains to the São Francisco through the Rio Pardo, an affluent of the Rio das Velhas, the Duro to the Jequitinhonha through the Caethé-merim. Both the Pardo and the Caethé-merim, but particularly the latter, are famous diamond streams.

The material exposed in the mines is a soft, soapy clay that is graphically described by Burton[1] as follows. "The material is a hardened paste of clay, whose regular and level stratification argues it to have been deposited in shallow water. The eastern side of the gap is the more ferruginous formation (terra vermelha); on the west it is mixed with beds of white sand. Below one foot of brown soil the argillaceous matter has the usual staining and marbling, glaring white like fuller's earth, with feldspar and kaolin, chocolate-brown or rape-colored with organic matter, blue-green with traces of copper [?], pink and rose purple, and dark yellow with various oxides of iron, especially hematite, and dark steel color with oxide of manganese [?]."

In the whole extension of this immense cutting, nothing approaching the gravel, the usual characteristic of a diamond mine, is to be seen and, with the exception of quartz veins, it is difficult to find a specimen that will resist the pressure of the fingers. The structure as exposed on the sides of the cutting, is much obscured by slides and weather action, and Burton's mistake of horizontal stratification and other indications of a shallow water deposit (thus corresponding, except in the character of the material with the other diamond deposits of the region and with the preconceived ideas of his informants, the miners) was a natural one on the part of a non-geological observer. The true nature of the clay as a decomposition product of schistose rocks had already been clearly recognized by Heusser and Claraz, who first described the mine and who iden-

[1] The Highlands of the Brazil, London, 1869, II, p. 129.

tified the original rock type as hornblende-schist,[1] giving the impression that the diamond occurred throughout the whole mass. The limitation of the diamond to certain streaks, or layers, was recognized by Burton, who gives the following excellent description of them.

"The richest lode (*corpo*) is No. 3, or the highest. The strike of the ribboned clays is north and south, bending [dipping] eastward. The lode inclines towards the higher grounds, and thus the owner hopes to find the gem-bearing strata spreading over the crest or watershed ridge which forms his property. Through the ferruginous sandstone (*borra*) and the white feldspathic matter run dikes and lines of fragmentary rock crystal, sometimes fibrous like arragonite, and often finely comminuted. Large pieces of imperfect specular iron and thin strata of quartz, yellow and brown at the junction, thread the argile, and I was shown a specimen of fine sandy conglomerate, blackened and scorified by the injection of melted matter.[2] The characteristics of this upper lode are a dryer clay, silica, a trace of copper [a green silicate of the nature of chlorite or serpentine?], of iron cement, and of Canga in small pieces; when the specular iron is in large pieces and abundant the rock is rich in gems. Its 'agulhas' [rutile] are iron-like bundles of needles welded together by intense heat; some are double, the fibers coming at obtuse angles. The 'Agulhas Cor de Ouro' have a burnished coppery surface, whence the name. Throughout all these corpos the diamonds are small, averaging perhaps a little under one grain or 64–72 per oitava; they are mostly crusted superficially

[1] Although Rose failed to find hornblende in the material submitted to him by Heusser and Claraz, it is possible that this idea was not entirely without foundation. Throughout the whole region traversed by them, intercalations and dikes of amphibolic and pyroxenic rocks are frequent in the schist series and generally they are the only ones of the not distinctly quartzose rocks whose original composition can be readily determined. As they usually give green decomposition products the staining referred by Burton to copper may, with considerable plausibility, be attributed to them. To judge from other exposures, the absence rather than the presence of such rocks at São João da Chapada would be a motive for remark.

[2] Probably a "Canga" or mass of sand or clay cemented by limonite common in such deposits.

with a light green tinge. Lower down we came to the middle or second body. Here the 'tauá' (feldspathic clay) was stiff and sandy, marbled with a fat, blue, muddy marl, which leaves upon the fingers a greasy, steely streak. It also yields a dark olive-green argile harder than the rest; like all the others it has consistence in situ, but when removed it crumbles to pieces after drying. Lieutenant-Colonel Brant gave me from this corpo a fragment of hard, large-grained clay, reddish colored with oxide, and showing a small brilliant imbedded in it. We then descended to the lowest formation. Here the clay contains very little sand, and much stained; the colors are white and blue, red and yellow, rosy, spotty, and in places dyed as with blood. Here also are found the 'Agulhas' in streaky bundles of iron-like asbestos. The sole of the pit is uneven with working, and in places 'horses,' 'old men,' and long walls of stiff clay have been left standing amongst the holes and gashes. From this point the several lodes are distinctly traceable in the walls of the basin." A more technical description is given by Gorceix[1] as follows: "One of the beds of bluish black color is composed of clay impregnated with oligiste in small fragments with rutile and anatase; the second of lithomarge with entire crystals of quartz having the same aspect as those of the topaz mines [near Ouro Preto]; the third and most important, with a thickness of more than 1.50^{m}, is composed of a series of beds of mottled clay. The stratification planes, parallel to those of the quartzites, are still clearly visible; the layers are undulated, folded like those of the intact schists that are found a few meters distant. Fragments of schist still almost intact occur in the midst of the clay. These beds of clay are traversed by small veins of quartz, granular or in bipyramidal crystals, oligiste and rutile, showing no signs of wear. Octahedral oligiste is found in certain points in extreme abundance impregnating the rock; in other points it is substituted by ordinary oligiste. The aspect of the gravel resulting from the washing of this clay is entirely different from that of the alluvial deposits, though composed of the same elements. The

[1] Comptes Rendus, 1881.

diamonds themselves of this region are easily distinguished from those of the rolled deposits by their rugose faces, sharp angles, and superficial greenish blue coloration."

On the occasion of my visit in 1881 only fallen masses that appear to represent the bodies 3 and 2 of the above description were to be seen, the operations of the mine being at that time suspended. One of these masses was so evidently a section of a vein that the conclusion was announced[1] that at São João da Chapada the diamond is a vein mineral accompanying quartz and an argillaceous rock of indeterminable character in the series of metamorphic schists. This conclusion was subsequently fully confirmed by Gorceix as the result of prolonged prospecting operations,[2] and thus one mode of occurrence of the diamond in the matrix was clearly established which, in appearance at least, is widely different from that at Gão Mogol and at Kimberley.

In the various papers by Gorceix and myself the schistose series of the gold and diamond region of Minas Geraes, in which the diamond occurs at São João da Chapada, is assumed to consist essentially of metamorphosed clastics, though no direct proof of this assumption is given. As regards the diamond-bearing layers, they are called veins, but no definite opinion regarding their mode of origin is expressed. For the question of the genesis of the diamond both these points are important.

All writers on the geology of this region are agreed that the characteristic formation is a great series of phyllites, quartz schists (itacolumite), iron-mica schists (itabirite), and limestone, and that this series constitutes a geological unit. This last point is assumed rather than proven, since there may be a break in the succession which has thus far escaped observation, just as that above indicated between the upper and the lower itacolumite was overlooked, or disregarded, by the older writers. For the purposes of the present discussion, however, it is of little conse-

[1] Am. Jour. Sci., 1882, Vol. XXIII, p. 97.

[2] Comptes Rendus, No. 25, 1881. Am. Jour. Sci., 1882, Vol. XXIII, p. 97, and Vol. XXIV, p. 34.

quence whether the series as here limited by the exclusion of the massive itacolumite of Eschwege is a simple or a composite one, since the evidence as to origin applies very directly to the beds in question exposed in the diamond mine itself.

As recent studies in various parts of the world on schists of doubtful character have proved that the schistose structure is not, as was long supposed, an unequivocal proof of a clastic origin, an attempt has recently been made to find in the rocks themselves internal evidence for or against the hypothesis of such an origin. As is well known, most of the mineralogical elements of a metamorphosed rock, whether clastic or otherwise, are authigenic; others which in certain cases may be presumed to be allothigenic may have been broken up, recrystallized, enlarged by secondary additions,[1] or etched, so that all traces of the original worn surface of clastic grains may have been lost or so obscured as not to be recognizable with certainty. The hopes of finding such internal evidence are therefore limited to the rare accessories, and among these practically to zircon, not only on account of its almost universal distribution in sedimentary deposits, but also of its resistance to chemical changes. In the examination of the heavy residues of a considerable number of the rocks of the series in question, it was found that in rocks of their character and degree of metamorphism, zircon is the only element that can be depended upon to give unequivocal evidence as to the mode of origin. All the other constituents, principal or accessory (quartz, mica, iron, and titanium oxides, tourmaline, disthene, etc.), present the fresh appearance of authigenic elements, as most of them doubtless are, though in some cases this appearance may be due to the fragmentation, regeneration, or etching of original clastic grains. On the contrary, the zircons in the considerable number of residues examined have failed to show evidence of secondary modification by any of the processes

[1] As will be shown elsewhere, tourmaline may be regenerated by secondary enlargement in the same manner as in the well-known case of quartz. A remarkably fresh appearance of the surfaces of quartz grains, due to etching, is noticeable in the washings from the clays of São João da Chapada, but it is to be presumed that this is a phenomenon of decomposition rather than of metamorphism.

mentioned so that, when present, their evidence is positive when they show distinct signs of wear, doubtful when these signs are absent or dubious.[1]

Applying the zircon test to the material at hand from the São João da Chapada mine the evidence for the clastic origin of the greater part of the original rock types from which the clays are derived has proved to be unexpectedly satisfactory. A number of samples of typical clays, including some reputed to be diamantiferous, afforded zircons which in abundance, size, and amount of wear, are comparable with those of the granular quartz rock (itacolumite) that occurs above the schists in the immediate vicinity of the mine. To judge from the number and character of the zircons, these samples represent original grits rather than more purely argillaceous material as was supposed from their present character and appearance. This conclusion is confirmed by the amount and size of the quartz grains (beautifully etched) that are also separated by the washing of the clay. In a miner's concentrate representing mixed material, fresh, prismatic glassy zircons occur mingled with the ordinary rounded, reddish clastic type indicating that other types of rock, presumably eruptive, may be represented among the clays. For the present discussion, however, the essential point is that the generality of the zircons of the clays are worn, thus confirming the assumption, based on stratigraphical evidence, that the clays of the mine represent a series of schists of which the predominant types are of clastic origin. This conclusion, however, does not exclude the possibility of subordinate intercalations,

[1] The rounding of the angles alone cannot be taken as an unequivocal sign of wear, as it is often an original feature of the zircons of undoubted eruptive rocks. When the angles are rounded by attrition the faces are also dulled in a manner that is readily distinguishable from that produced by malaconization. Undoubted clastics occur in which the signs of wear of the zircons are inappreciable, either because the amount of transportation has been too small or the material too fine to produce them, or because they have been involved in other elements, as in the case of arkose and tuffs. In the case of argillaceous rocks the rarity and minuteness of the zircons may be an argument in favor of a clastic origin even when they show no distinct signs of wear, but the evidence is not conclusive as they are minute and rare in some eruptives as well.

or injections, of eruptive origin, which, judging from eviden elsewhere, are rather to be expected than otherwise in a cutti like that of São João da Chapada. For the question of t genesis of the diamond this hypothesis is of prime importan and the evidence thus far available for or against it will now examined.

Of the three diamond-bearing bodies described by Burt and Gorceix only two were seen by me. The masses shown r were displaced by landslides, but, as nearly as can be dete mined, they represent the middle and lower bodies of Burton.

The mass supposed to represent the lower body of Burt and the mottled clay of Gorciex consisted of a considerab rectangular block of quartz, with plates of specular iron, a with laminated clay representing the decomposed country ro adhering to it on one side. On the other side was a mass friable structureless reddish clay, sharply defined on the si opposite the quartz from the harder laminated clay of t decomposed country rock, which is here also reddish, but of different tint and aspect. The whole appearance of the ma was that of a vein with sharply defined walls, and it was described on account of the quartz, though, as the earthy po tion was referred to a decomposed rock of undetermined cha acter, the term dike might have been employed with equ propriety. The earthy diamond-bearing mass was shown consist of an argillaceous portion stained with iron oxide and sandy portion with quartz and tourmaline. The heavy resid which has since been separated and examined consists princ pally of aggregations of specular iron and of a micaceous miner representing some altered silicate with a great abundance microscopic brown tourmaline. Yellowish, burr-like aggregat of anatase are also abundant, while rutile is comparatively rar as are also grains of disthene. All of these minerals are ev dently authigenic. The rare grains of zircon are in pa distinctly worn, in part with the fresh appearance of an auth genic element. A few grains of staurolite also occur, and the are, for the most part, rounded, giving them a worn appearanc

but as some of them are distinctly etched, it is thought that this aspect may be due to etching rather than to attrition. Unfortunately, it is not absolutely certain that the zircon and staurolite may not have been introduced from a foreign source, as at the time the washing was made the extreme care now found necessary to avoid admixture was not observed. On the assumption that the residue is a pure one (as it is believed to be),[1] the interpretation would be that the original vein material contained primary tourmaline and zircon with iron and titanium minerals that have furnished material for secondary hematite, anatase, and rutile, and that the accompanying schist contained clastic zircons, staurolite that is authigenic if the rounding of the grains can be attributed exclusively to etching, and disthene. The hypothesis that best suits these conditions is that of a granitic (pegmatitic) vein accompanied by phenomena of contact metamorphism.

The mass that was shown to me as representing the Barro Preto (black clay, middle body of Burton) had the characteristic of a bed rather than of a vein. The clay is well laminated, ribboned with fine regular alternating streaks of white and black, the latter composed mainly of a fine powder of hematite. The residue, freed from clay, shows a great abundance of black hematite, so finely divided that much of it floats away in the washing, a moderate amount of etched quartz, a small amount of tourmaline in coarser grains than in the body above described, and a comparative abundance of rolled zircons, which appear also to have been somewhat malaconized. The titanium minerals, rutile and anatase, are absent, or extremely rare. A sample subsequently received as representing the same body agrees substantially with the above, except in the greater abundance of quartz and the absence of tourmaline. All these indi-

[1] In the case of an admixture, rounded staurolites and fresh disthenes are not the minerals that might be expected to be introduced in the residue through lack of care in the preparation. Two or three grains of monazite were found that were certainly introduced by accident, but this very circumstance gives confidence in the general purity of the residue, as the much more abundant disthene and staurolite are not its usual associates.

cations point to an original bed of sandy ferruginous shale rather than to a vein.

The third body, not seen by me, is, according to both Burton and Grociex, characterized by a white feldspathic clay, kaolin, or lithomarge, with crystals of quartz and specular iron. Specimens exactly corresponding to this description were kindly furnished by Dr. Thomassi Bezzi, who collected them with the assistance of the owner of the mine, so that their authenticity is undoubted. Two specimens representing the Barro and the Duro mines are practically identical. In both a mass of snow-white, structureless clay, with nests of quartz crystals and specular iron, has adhering to it colored laminated clays. The contact between the two, sharply defined by the strongly contrasted coloration, is in part linear, in part irregularly undulated, but without appearance of graduation from one to the other. Irregular stringers of the white clay penetrate the mass of the colored, and irregular masses of the latter are inclosed on the former. The whole appearance of the contact is that of a vein or dike, represented by the white clay, with stringers and inclusions of the country rock. The contrast between the heavy residues of the two kinds of clay is as striking as that of their coloration and general appearance. Corresponding quantities taken at a distance of a few millimeters from each other or either side of the contact gave very different residues, both as regards quantity and mineral composition. That of the white clay is extremely small, consisting, aside from rare grains of quartz and specular iron that apparently come from segregations rather than from the body of the clay, exclusively of delicate needles of yellow rutile, the *Agulhas cor de ouro* (golden needles) mentioned by Burton. The residue from the colored clay is, on the contrary, abundant, consisting, after the separation of the quartz (beautifully etched) and iron oxide, of rolled zircons, anatase, tourmaline, and iron-stained earthy grains of rudely prismatic form that evidently represent a decomposed silicate, possibly staurolite. This last is a characteristic residue of a metamorphosed clastic rock, and as tourmaline and anatáse seem to be

present in abnormal abundance, contact metamorphism is strongly suggested. The residue of the white clay, on the other hand, gives no indication as to its origin, since the only characteristic accessory found in the small quantity available for washing is rutile, which is so widespread and varied in its mode of occurrence and association as to be indeterminative. One of the washings from the colored clay gave two types of zircons, the usual round, much worn reddish ones, and less worn whitish elongated prisms. The latter resemble those already mentioned as occurring (with a fresher appearance, however,) in a miner's concentrate, and still more closely those of a partially decomposed rock from the Sopa mine in the neighborhood (where lithomarge also occurs, but is not known to be diamantiferous), which strongly resembles the European "porphyroid," and is either metamorphosed arkose or porphyry, probably the former.

This white clay, in the character of its material and of its contacts, and in the lack of characteristic clastic elements, is strongly suggestive of the so-called pegmatite veins that are of frequent occurrence in similar formations and under similar conditions. The quartzose character of some of the veins, or parts of veins, is not inconsistent with this hypothesis, as the intimate relations and interdependence of quartz and pegmatite veins are well known. The indications furnished by this body are therefore in accord with those of No. 1—that is to say, that the vein matter was probably originally pegmatitic, and that it was accompanied by phenomena of contact metamorphism.

So far as can be made out from the observations thus far made on material the most unsatisfactory that can be imagined (foliated and highly modified by dynamometamorphism and afterwards totally decomposed so as to present, in its present state, one of the most intricate problems of mud geology), the most plausible hypothesis as regards the various clays of the São João da Chapada mine is that they represent an original group of phyllites of varied character, but principally, if not exclusively, of clastic origin, threaded with veins of pegmatite.

The possibility of an admixture of originally eruptive eleme in the phyllites themselves is, as already noted, suggested by t supposed copper staining of Burton and also by the harder oli green clay that he mentions as occurring with the second bo The only rock specimen that has come to hand from the min a small fragment of a sericitic schist that, aside from a very f dust of hematite, gives no residue whatever, and which may suspected to be a metamorphosed eruptive.

On the hypothesis of the original essentially pegmati character of the diamond-bearing bodies of São João da Chapa three important questions arise which can only be solved hy thetically. What was the original type of the pegmatite? it eruptive or secretionary? Do the diamonds belong to it or the country rock in its immediate vicinity, and perhaps modifi by it, or to both?

Bodies of pegmatite are quite common in the older rocks Brazil, both in the diamond regions and elsewhere, occurri not only in the gneiss and granite, but in the schistose series well. Those that have been examined are dike-like in their mo of occurrence and granitic in composition. They are alm universally decomposed, affording a pulverulent kaolin, not t indurated type of lithomarge. Their residues are usually abu dant and typically granitic, representing more particularly t type of the muscovite granites, consisting of zircon, monazi and almost invariably xenotime. All of these characterist (which, however, may not be essential) are lacking in the su posed pegmatitic clay of São João da Chapada, in which or the presence of quartz is suggestive of granite affiliation. the other hand, however, they are compared with great proprie by Gorceix with the topaz-bearing clays of Ouro Preto, a topaz is generally regarded as a granitic mineral. Topaz h not been reported from São João da Chapada, but in one was ing from a mixed sample of the clays a minute grain w observed that in form, optical properties, and specific grav seems to agree with that mineral. The other known types pegmatite — those affiliated with syenites, diorites, and gabbr

— have not as yet been definitely identified in Brazil, though they doubtless occur. The apparent absence (or extreme rarity) of zircon may perhaps be taken as indicative of gabbro, and considerable masses of this type of rock, to which the supposed pegmatite might be referred as apophyses, are known to occur in the diamond region. So far as known, however, this is the utmost limit in the direction of basic rock types to which one can go, even hypothetically, in seeking the probable original type of this supposed pegmatite.

The question of the eruptive or secretionary origin of pegmatites has long been a subject of discussion among geologists, and eminent authorities can be cited in favor of either view. The recent studies of Lehmann, Brögger, Williams, Crosby, and others seem to have clearly established that most if not all of them are essentially eruptive masses, though possibly modified in some way by aqueous agencies. Even before becoming acquainted with the literature of the subject this view had seemed to me to be the only acceptable one as regards the typical pegmatites of Brazil. The extension of it to such problematic occurrences as the diamond-bearing bodies of São João da Chapada and the topaz-bearing bodies of Ouro Preto cannot as yet be fully established on account of the lack of complete studies in the field and the decomposed condition of the material. Aside from the general analogy that they present with typical pegmatites, nearly all the criteria given in the recent papers by Williams and Crosby and Fuller in support of the hypothesis of eruptive origin can be cited in favor of the same hypothesis as applied to these bodies. If, as is suspected, they present phenomena of contact metamorphism, a crucial test can be applied through the study of the heavy residues of the enclosing schists at different distances from the contact. This, however, involves field studies that for the present cannot be undertaken. As the case stands at present the hypothesis of an eruptive origin, though not fully proven, is by far the most probable.

The response to the third question is still more unsatisfac-

tory than those to the other two. At the time of Burton's visit the most typical pegmatitic body was regarded as the richest of the Duro mine and in his description of the Barro mine he states that the white clay (called *diz*, or chalk, by the miners) served as a guide to the diamond formation. It is by no means certain, however, that the diamonds actually occurred in it rather than in the adjacent colored clays in contact with it and for which it serves as the most apparent guide. In the specimens at hand the part considered as the contact zone is mineralogically the richest, and it may be suspected that the diamonds occur in it rather than in the white clay. The lower body reputed to be the richest at the time of Gorceix's visit is, according to his description and that of Burton, much less decidedly pegmatitic in aspect and the part seen by me seemed to be a decomposed dike with no apparent suggestion of pegmatite. The part of this body indicated to me as diamantiferous belongs certainly to the supposed dike and not to the contact zone. The other body, the Barro Preto, seems, according to the descriptions and the part seen by me, to be a specialized layer of the phyllites the relations of which to the pegmatites (if it has any) are not clear. In short the question as to whether the diamond occurs at São João da Chapada exclusively in the supposed pegmatitic bodies, in the contact zone of said bodies, in layers of the phyllites more or less removed from such contact zones, or in all, must remain an open one.

As the case stands at present the indications seem to be rather in favor of the hypothesis of the formation of the diamond in the phyllites, the presumptive agent being the supposed eruptive which in some of its phases presents a pegmatitic character. This involves, presumably though perhaps not necessarily, the supply of the necessary carbon from the phyllites themselves, but as the series is known to include in many places graphitic members such a supply may reasonably be predicted at São João da Chapada. Moreover the evidence from Kimberley, where, according to Launay (*Les Diamants du Cap*), the rock considered rich only yields one part of diamond to 3 mil-

.ion to 36 million parts of rock, indicates that the amount required is so infinitely small that few rocks can be conceived that may not contain, in some form, the necessary supply of carbon. The amount of this element that presents itself in the form of carbonates in the decay of many rocks, that in their sound condition are not recognized as containing it in any form, is far in excess of that here indicated as necessary. In this connection it may be remarked that the hypothesis that attributes a preponderant importance in the genesis of the diamond to the carbonaceous shales of the upper part of the Kimberley section, is subject to the criticism of furnishing a preposterously enormous superabundance of raw material.

The three localities above discussed offer no certain indications of more than one mode of genesis of the diamond in Brazil. The occurrences at Grão Mogol and Sãn João da Chapada can very easily be brought into line on the hypothesis, which has much in its favor that at the former place the diamond is an allothigenic mineral derived from deposits similar to those at the latter. For São João da Chapada and Agua Suja the comparison presents no difficulty if the diamonds at the last place are assumed to come, as is quite possible, from the underlying schists. If, however, they are genetically related to the later eruptive series, the hypothesis of a substantially similar mode of genesis requires that the predominant factor be an eruptive rock, which may vary greatly in its mineralogical character and mode of occurrence.

As compared with the Kimberley occurrence that of São João da Chapada seems at first sight to be characterized by an almost absolute lack of analogies. Until quite recently the only known feature at Kimberley offering some remote resemblance to the Brazilian fields was the presence of a quartzite in the lower part of the section. This resemblance is somewhat increased by the later developments as metamorphic schists appear mingled with the quartzite in the lower levels of the deep shaft (see section on p. 137 of Launay's *Les Diamants du Cap*). For the present the information regarding these lower

rocks is very meager, and further developments must be awaite to determine whether or not this resemblance has any speci significance. Another point in common that may prove to l of greater significance than at first sight appears is the occu rence mentioned by Carvill Lewis[1] of tourmaline and disther which seem to be formed by metamorphic action about inclose fragments of schist. It is true that disthene is not a speciall characteristic mineral at São João da Chapada, but it extremely widespread and abundant in the schist series in whic the mine is excavated, and of the aluminous silicates, is th most constant and characteristic of the associates of the di mond in the Brazilian alluvial washings. The significance, any, of its persistent association with the diamond (now ver fied at Kimberley) is that of a mineral characteristic of th metamorphism (by contact or otherwise) of argillaceous rock

In order to bring the Kimberley and Brazilian mode occurrence into line as phases of a single mode of genesis, seems necessary to put aside the idea that the recent interestin experiments on the artificial production of the diamond afford solution of its terrestrial origin, and that the Kimberley type rock and mode of occurrence are essential features. Presum ably also the genesis must be sought in the rocks affected b the eruptive masses rather than in those masses themselve There are still many obscure points about both places, and unt these are cleared up no satisfactory comparison can be mad At São João da Chapada there is little prospect of working bein resumed so that no additional light is to be expected fro there, but at Kimberley the workings may ultimately reach depth that will give a complete solution of the problem for th place and mode of occurrence. When this occurs, if it is ver fied that the ultra basic type of eruptive rock, brecciated struc ture, and slot-like mode of occurrence are necessary feature the Brazilian occurrences must be put into another category.

ORVILLE A. DERBY.

SÃO PAULO, November 29, 1897.

[1] Papers and notes on the genesis of the diamond.

THE GLACIATION OF NORTH CENTRAL CANADA.[1]

I WISH very briefly to place before you a statement of what would seem to me to have been the conditions that prevailed during at least part of the glacial period in the great Central Plains region of Canada, but before going farther I take great pleasure in acknowledging my indebtedness to Professor Chamberlin, Mr. Warren Upham, and many other glacial geologists of the United States, whose work is so closely connected with mine, and who have so clearly expounded many of the principles on which my explanations are based. It is an especial satisfaction to me to feel that the results of my investigations accord so well with theirs.

In the preparation of the slides here shown I have freely used the published works of these geologists, and of Dr. Dawson and Messrs. McConnell, Low, and of our own geological survey, when depicting the conditions that prevailed in those portions of the country which have not come under my own personal observation.

That portion of Canada, to which I propose to refer for a few moments, lies between west longitudes 85° and 130°, and north latitudes 49° and 69°; or perhaps it may be more intelligibly located as being bounded on the east by the west coast of Hudson Bay, and a prolongation of the same line southward, and on the west by the Rocky Mountains, the average distance between these two lines being about 1100 miles; on the south by the international boundary, and on the north by the Arctic Ocean, which are an average distance apart of 1400 miles, giving a total area of about 1,500,000 square miles.

This vast region has a remarkably even surface contour, with a mean elevation above the sea of about 1200 feet, and slopes gently from the foot of the Rocky Mountains northeastward to

[1] Read at the Toronto meeting of the British Association, August 1897.

Hudson Bay. The contour lines here shown are respectively 600, 1500, and 3000 feet above the sea, and from the 3000 feet contour line the surface has an average slope of a little less than three feet to the mile. This slope is of course not quite regular, being broken by hills and valleys, and occasionally the country rises for some considerable distance in the opposite direction, but on the whole the general decline is very well marked, and no high mountains break the general monotony of the landscape.

In the more northern portion of the region are the treeless plains; or "Barren Lands," extensive level or undulating grassy plains, with a mean summer temperature below 50° F., and with a frozen subsoil which prevents the growth of trees. South of this is the great forest region, the home of the chief fur-bearing animals of Canada, and still farther south are the plains or prairies, which many of you will probably cross on the transcontinental railways after the close of this meeting.

It would be beyond the scope of this paper to discuss the question of rainfall, but suffice it to say that the humidity of the atmosphere decreases from the seacoast inland, and while the Barren Lands are kept constantly wet by fogs and drizzling rains, the air over the prairies is very dry, and licks up rapidly any moisture that may be lying on the surface of the ground.

As you will see from the handbooks prepared for the use of the members of the association, the northeastern part of this region is underlain by crumpled and distorted Archæan rocks, whose surface has, even in pre-Cambrian times, been reduced to an undulating plain, with very slightly accentuated contours. On each side of this elongated area, or low central ridge, of highly altered Archæan rocks, are flat-lying limestones, sandstones, and shales, varying in age from the Cambrian up to the Tertiary, and separated by several erosion intervals, which, with the water-deposited strata, would indicate a gradual rising and lowering of the land along a line parallel to the present Archæan outcrop. From a study of the Rocky Mountains, and the mountainous region of British Columbia,[1] Dr. Dawson has shown rea-

[1] On the Later Physiographical Geology of the Rocky Mountain Region in Can-

sons to believe that the oscillations of the land were exceptionally rapid in early glacial and immediately preglacial times. But it would seem probable that the drainage has always followed the main valleys which still trench the surface, running more or less at right angles to the mountains.

The pre-Cambrian valley of Chesterfield Inlet, extending eastward towards Hudson Strait, and westward towards Great Slave Lake, and the post-Cretaceous valley of the Saskatchewan, extending towards the lower valley of the lower Nelson River, and many other valleys running more or less parallel to these, go to prove the general correctness of this statement.

In the opinion of the writer almost all of this country was overspread by the Keewatin glacier, which centered in what is now the comparatively low country west of Hudson Bay. Evidences of its presence may be seen almost everywhere in striated rock surfaces, giant's kettles, widespreading sheets of unstratified till, stratified inter-till deposits, moraines, eskers, and transported bowlders.

The causes of the great cold of the glacial epoch are yet enshrouded in mystery, and the most that has been suggested is that if such and such things had been so, if the land had been higher here or lower there, ice would have accumulated in northern latitudes, but as yet there is little or no proof that such conditions did exist. At present it would appear to be much more satisfactory to spend our energies in endeavoring to follow up the traces left by the glaciers and lakes of the glacial epoch, and to first determine the conditions that existed at one time, or the order in which certain conditions existed, rather than to devise elaborate theories to account for conditions that may never have occurred. When the country has been thoroughly examined, and the glacial deposits, striæ, etc., are well known, the proximate causes of these phenomena will in all probability be easily determined.

The information with regard to the conditions of glaciation

ada, by George M. Dawson, Trans. Roy. Soc. Can., Vol. VIII, Sec. 4, pp. 1–74. Ottawa, 1890.

unearthed is undoubtedly but a very small portion of what wi be known when our country is more fully explored, for com pared to the vastness of the field and the probable extent of th harvest of knowledge, the harvesters are indeed very few. Th observations here discussed have been made by the writer dur ing the past thirteen years, but as individual records are difficul to grasp and remember, I have attempted to connect them i such a way, and to bring them graphically before you, so tha you may form a clear idea of the results that have been attained and at the same time I shall endeavor to state very briefly som of the evidence on which those results have been based, so tha you may distinguish between the records and the connectin theories.

Up to the present time three great continental glaciers hav been recognized in Canada, viz., the Cordilleran, which covere the western mountains and their intervening plains, from lati tude 49° to latitude 66°; the Keewatin, which covered the grea plains east of the mountains; and the Labradorean, which sprea over northeastern America from a center in Labrador.

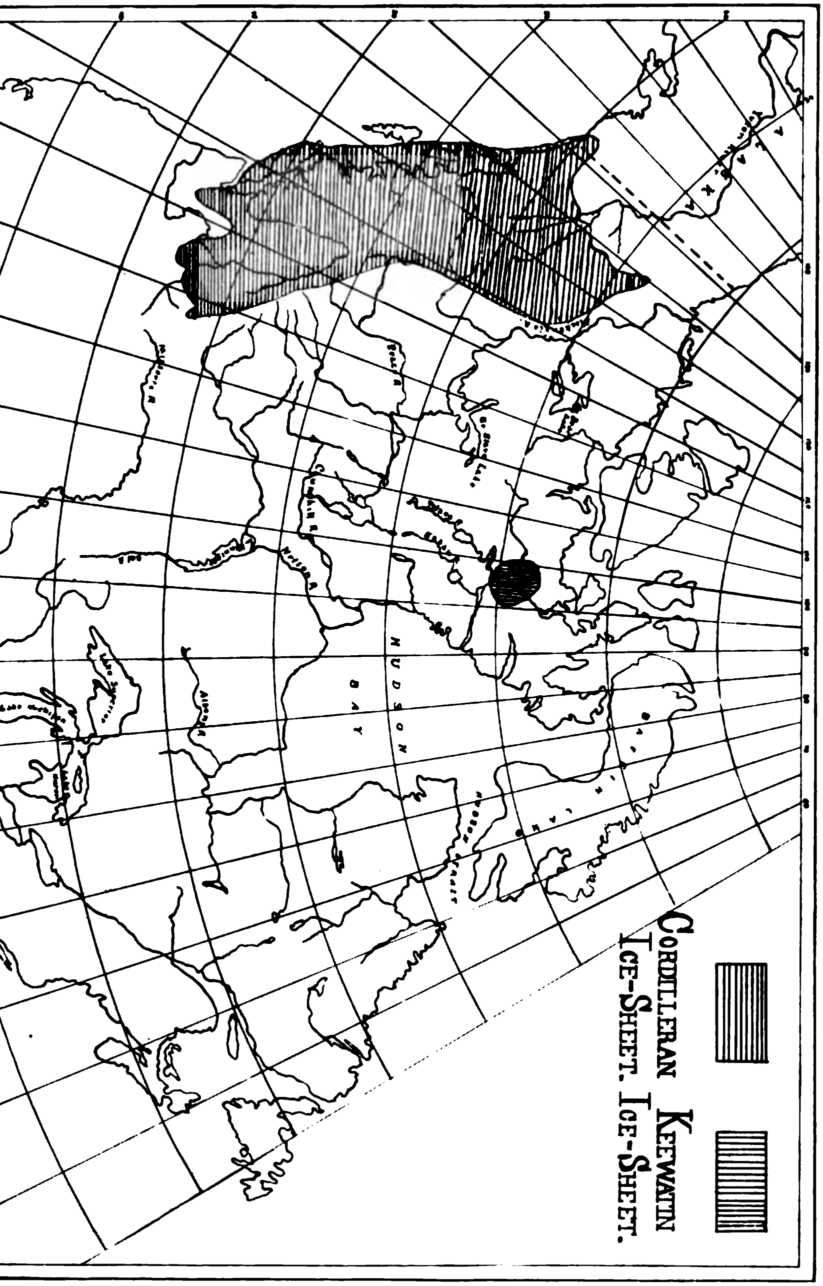
The earliest till as yet recognized in Western Canada, eas of the Rockies, has been called by Dr. Dawson the Alberta Deposit,[1] and has been shown by him to have been formed b tongues of the Cordilleran glacier, which extended outward towards the plains through the transverse valleys of the Rock Mountains.

The illustration shows the greatest extent of this Cordillera glacier as defined by Dr. Dawson.

From the fronts of these glacial tongues streams rushe eastward, carrying with them large quantities of coarse detritu which were soon deposited in the bottoms of the valleys as bed of coarse, well-rounded gravel, called by Mr. McConnell th Saskatchewan gravel, this gravel and the Albertan till bein directly traceable into each other.

The Cordilleran glacier then withdrew; but whether it entirel

[1] Glacial Deposits of Southwestern Alberta, by GEORGE M. DAWSON and R. C McCONNELL, Bull. Geol. Soc. Am., Vol. VII, p. 66, Rochester, 1895.


CORDILLERAN ICE-SHEET.
KEEWATIN ICE-SHEET.
HUDSON BAY

disappeared, or merely confined itself to the west side of the Rocky Mountains, I do not know, but at all events it seems to have ceased to be an important element in molding the features of the plains.

After the withdrawal (or possible disappearance) of the Cordilleran glacier, the Keewatin glacier overspread the country, radiating outwards from a center probably lying somewhere between Doobaunt and Back rivers. The till formed during this period, which is probably synchronous with that of the sub-Aftonian period of Professor Chamberlin, may be easily recognized in the scarped banks of many of the streams in Alberta, where it overlies the Saskatchewan gravel of the Albertan period. It is composed largely of material derived from the underlying Cretaceous and Laramie rocks, but at the same time it contains a considerable quantity of other material transported from a distance, some of which, consisting of granite, gneiss, quartzite, and similar rocks, has been derived from the Archæan nucleus to the northeast, while some has been derived from the Cambrian sandstones, and Cambro-Silurian and Silurian limestones that extend around the edge of the Archæan.

After the deposition of the sub-Aftonian till the Aftonian period of deglaciation set in, during which the Keewatin glacier became greatly diminished, and interglacial deposits were laid down, both in extraglacial lakes, and in lakes and swamps at some distance from the face of the glacier. How far the foot of the glacier withdrew in this interglacial time I do not know, but I am inclined to think that most of Manitoba still remained covered with ice, for in the western part of that province I have not been able to find evidence of more than one main Keewatin interglacial period, which is probably later than the Aftonian period.

After this period of diminution the Keewatin glacier again began to increase, and it spread southward and westward until it had reached about the same limits that it had reached during the sub-Aftonian period, and had spread another sheet of till over the earlier till and subsequent interglacial deposits. The

period of this advance of the ice would seem to correspond to the Kansan epoch, as at present understood by American geologists. This till is very similar to that below it, but the material of which it is composed is more highly oxidized and decayed, and fragments of soft, brittle rocks, such as lignite, are much less common in it than in the lower till.

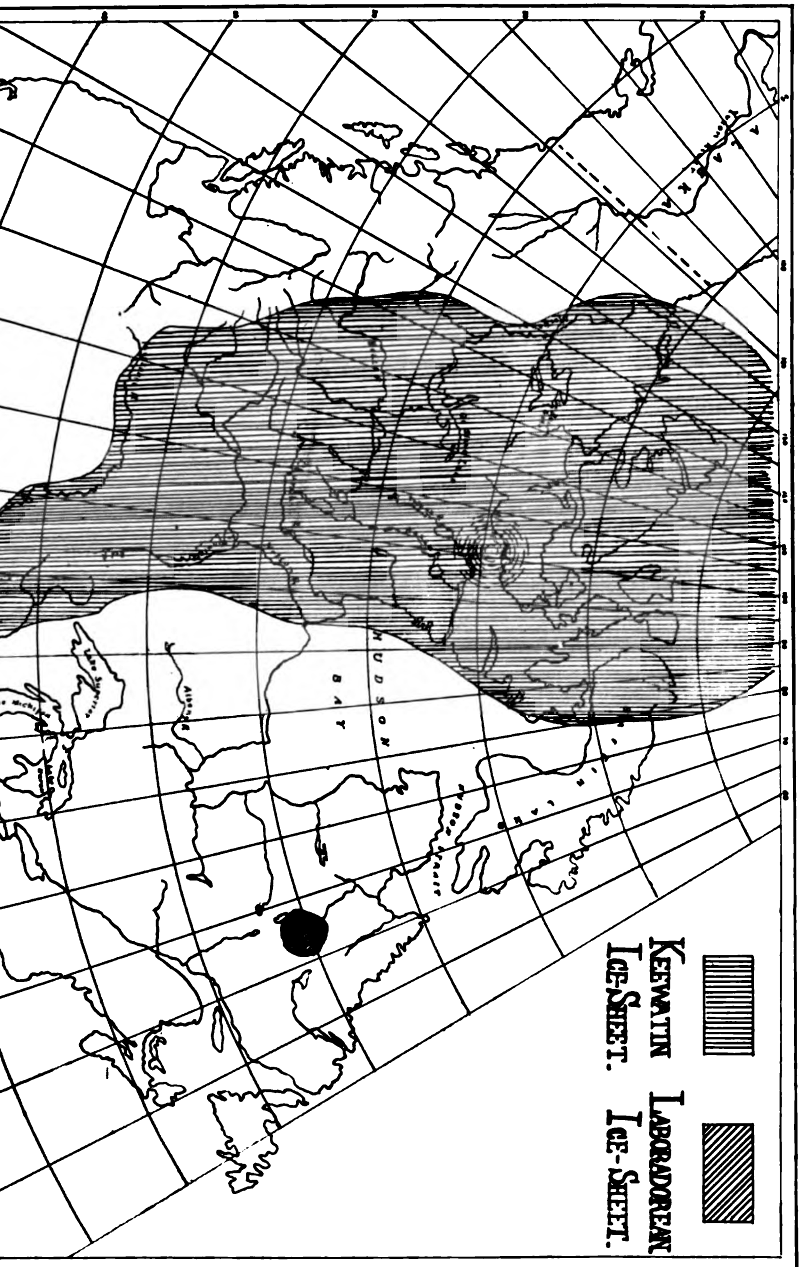
Both during the Kansan and sub-Aftonian epochs, extraglacial lakes of greater or less size doubtless existed, and any material brought down into them by the glaciers would doubtless have been scattered over their floors or along their sides. Thus bowlders were probably carried some distance beyond the extreme limits to which the glaciers themselves reached, as, for instance, on some of the terraces near, and at the foot of the Rocky Mountains where Dr. Dawson has recorded the occurrence of numerous transported bowlders. Where these lakes existed terminal moraines would also not be found, and thus the absence of terminal moraines may often be explained in places where we should otherwise expect to find them.

Striæ have not been recognized in this western district, for the soft Cretaceous rocks are not suitable for their preservation, but the older and harder rocks, nearer the center of the glaciated area, are everywhere scored with glacial markings. Around the periphery of this area underlain by harder rocks I have not been able to recognize more than one set of striæ referable to the Keewatin ice-sheet or rather more than one direction of striation, but nearer the glacial center several sets may be distinctly seen. Along the Doobaunt River above the Forks the oldest of these point southward, probably running outwards from a center between Doobaunt and Back rivers. These I have associated with the earlier stages of the Keewatin glacier, though I have no direct evidence to offer on that point, except that they are the earliest of four different and distinct sets of glacial striæ.

The accomplished geologists who have worked in the United States, near the headwaters of the Mississippi River, have found that there was an extended epoch of deglaciation after the deposition of the Kansan till, and I would assign to this interglacial

epoch a line of division in the till of western Manitoba, along which stratified deposits may occasionally be seen, but which is strongly marked in several places by beds of bowlders that have been sunk in the surface of the earlier till, and being there held firmly in place have been smoothed and striated by the later glacier which passed over them. How far the Keewatin glacier retreated during this second epoch of deglaciation is not known, but it is not improbable that it withdrew far north of the present northern boundary of Manitoba.

After this interglacial epoch the Keewatin glacier again began to increase, though its center of dispersion had gradually shifted southeastward until it now rested over the country between Doobaunt and Kazan rivers. From this center it flowed outwards in all directions, and its striæ may be seen on most of the rocky knolls throughout that whole northern country, running southward towards Lake Winnipeg, westward towards the Mackenzie River, northward towards the Arctic ocean, and eastward towards Hudson Bay. Everywhere the smooth-faced hills give evidence of its presence, and even in the absence of striæ, the evenly-rounded surfaces facing the glacial center, and the broken, craggy hills looking in the opposite direction, furnish convincing evidence of the direction of flow of the ice. As the glacier advanced southward it came in contact with the high escarpment of Cretaceous shales forming the Porcupine and Duck mountains in Manitoba, and part of it was diverted to the east of south along the great valley of Lake Winnipeg. This lobe appears to have extended southward into Minnesota, Dakota, and Iowa, and to have deposited a till which probably corresponds to what Professor Chamberlin has called the East Iowan Formation. The Palæozoic limestones of western Manitoba have been beautifully scored by the markings of this glacier, and its grooves and striæ were detected in many places around the shores of Lake Winnipeg. East of the shores of Lake Winnipeg the exposed surfaces of the Archæan rocks were carefully searched for this set of markings, but none could be detected. It therefore seems probable that the eastern edge of this lobe or portion of


KEEWATIN ICE-SHEET.
LABORADOREAN ICE-SHEET.
HUDSON BAY

the Keewatin glacier did not extend very far east of the present eastern shore of Lake Winnipeg, and it is also probable that throughout its advance there was a free drainage eastward into Hudson Bay.

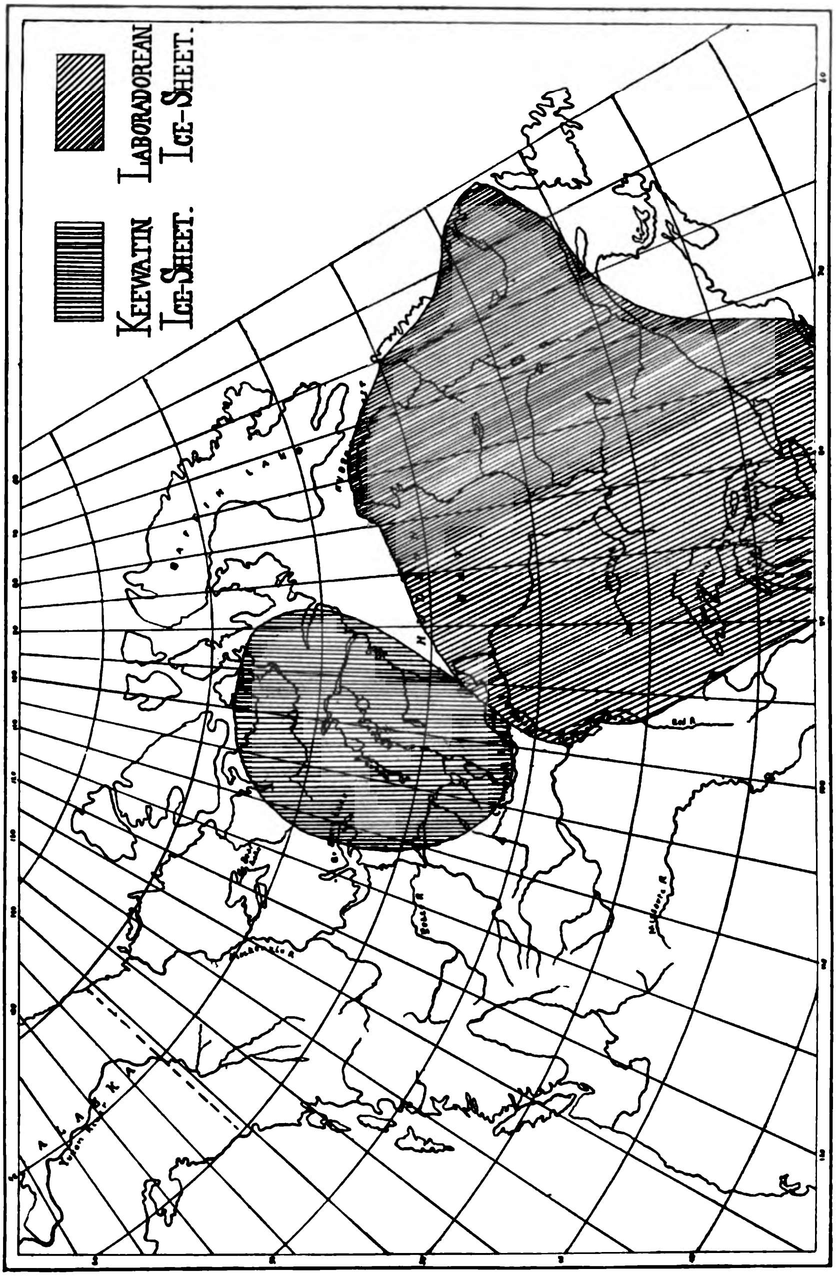
Traces of the existence of the streams that flowed eastward from the face or side of this glacier were found in several places in the form of deep potholes or giant's kettles, excavated in the summits or on the eastern slopes of knolls of granite, and gneiss where they could not have been formed under present conditions. At one place, on the south side of Berens River, several of these potholes occur on the east side of a granite knoll, one of them, at least, being ten feet in depth, and about thirty inches in diameter from top to bottom. The ten-foot hole was cleaned out, and was found to contain a great many rounded pebbles, all of Archæan rocks, some similar to the rocks of the surrounding country, and others that had evidently been transported from a distance. Both this and most of the other rocky hills where potholes were seen, have been scored and scraped down by the later glacier from the east, the outer sides of some of the holes having been cut away, leaving rounded niches in the faces of the smooth hillsides.

While a portion of the Keewatin glacier flowed southward in the Winnipeg basin, another parallel glacial stream would seem to have traveled southward between the Porcupine and Duck mountains on the east, and the rising land now marked by the Missouri Coteau on the west, both sides of this wide shallow depression being now at elevations of about 2200 feet above the sea. This glacial lobe probably extended southward into Dakota, and at its greatest extension it coalesced with the Winnipeg lobe over the summits of the Porcupine and Duck mountains, but for long periods, doubtless when the glacier was both advancing and retiring, the two lobes were more or less separated, and an extensive interlobate moraine was deposited on the summits of these hills. The Missouri Coteau is also considered to be the great moraine deposited along the west side of this lobe of the Keewatin glacier. Whether the glacier extended west of

ne Missouri Coteau during this period is uncertain, but there is strong morainic ridge extending from the Hand Hills north-estward by Sullivan Lake to the Beaver Hills, which may have een formed at this time. A high, stony, lumpy ridge about the ame elevation as the Missouri Coteau, and north of and more r less parallel to the Saskatchewan River, between it and the eaver and Athabasca rivers was doubtless formed a little later the same glacial epoch.

Now, confining our attention to the Winnipeg lobe of the eewatin glacier we find that after reaching its greatest extent a southeasterly direction it gradually retired northward, and s it retired a portion of the Laurentide glacier which had ccumulated in the country farther east, perhaps on the high and of the Labrador peninsula, advanced and the fronts of the wo united. The Keewatin glacier had probably retired well orth into Manitoba, and possibly beyond the northern confines f that province, before it was joined by the eastern glacier. fter they had united the water formed by the melting of the wo glaciers was ponded between their fronts and the high land o the south and west, and a large extraglacial lake was formed, hich has been called by Mr. Upham Lake Agassiz.

As the Keewatin glacier retired still farther, the eastern por-ion of the Labradorean glacier continued to advance and oblit-rated most of the marks left by its predecessor, but here and here, on the harder rocks on the east side of Lake Winnipeg nd farther north, distinct cross striæ were observed, where the ater glacier had not rubbed out all the earlier grooves and striæ. he later glacier reached to the west side of Lake Winnipeg, r in some places a little beyond, its front assuming a roughly obate form. Near the mouth of the Saskatchewan River the ill formed by both glaciers is well shown, but between the two s a thickness of 12 feet of stratified sand and clay, showing hat the Keewatin glacier had retired northward for a suffi-iently long time before the advent of the Labradorean glacier o allow of the deposition of this thickness of water-lain lake-eposits.


KEEWATIN ICE-SHEET.
LABORADOREAN ICE-SHEET.

Two hundred miles still farther north, along the Grass and Burntwood rivers, the striæ of the two glaciers cross almost at right angles to each other, the one being clearly later than, and independent of, the other. A little farther east, north of Gull Lake and Nelson River, is a long narrow sandy esker, from 90 to 200 feet in height, running east and west, clearly formed by one of the streams draining the Labradorean glacier. This ridge of loose sand would certainly have been swept away, if any glacier had advanced from the north subsequent to its formation.

Before the fronts of the two great glaciers had separated the eastern one had again begun to retire, and as it retired a thickness of from 50 to 100 feet of stratified clays and silts were deposited in the bed of Lake Agassiz, chiefly north of the present basin of Lake Winnipeg, for there some large streams draining the Labradorean glacier discharged into the lake, bringing with them a heavy cargo of glacial mud. The positions of these streams are still marked by long and high eskers, which may be seen near the banks of the Nelson River, crossing the country in a direction parallel to the later striation.

The Nelson River, in its northern course, from Playgreen Lake to Split Lake, marks the approximate eastern limit of this deposit of stratified clay, and along the eastern shores of Lake Winnipeg the stratified clays were not found at a greater height than 150 feet above that lake, and, except at one place, at no great distance back from its shore.

The absence of these stratified deposits would tend to show that the eastern glacier had not retired to any considerable distance east of Nelson River and Lake Winnipeg, before Lake Agassiz was drained by the gradual shrinkage of the Keewatin glacier to a small area in the vicinity of Doobaunt and Yath-kyed lakes.

Subsequently the Keewatin glacier appears to have broken into two or more smaller glaciers, the centers of which lay still nearer the coast of Hudson Bay than the center of the single glacier. One of these centers rested over the hills southeast of Yath-kyed Lake, and from it the ice radiated in all directions,

while another probably rested over the country north of Baker Lake and Chesterfield Inlet. Even at the present day it would take but a slight reduction in temperature, or a slightly greater precipitation, to cause that northern country to be covered with snow, for in the middle of August heavy patches of snow were seen resting on many of the hillsides and Doobaunt Lake was almost completely covered with a thick sheet of ice.

After the glaciers had been greatly reduced, or had entirely disappeared, the land west of Hudson Bay stood about 500 or 600 feet below its present level, and subsequently it gradually rose until it reached its present condition of comparative stability.

Whether the three great glaciers here referred to, namely, the Cordilleran, the Keewatin and the Labradorean, originated at the same time or not I do not know, and whether they waited for one another's disappearance or not I do not know; but this much appears certain that the Cordilleran glacier had reached its greatest extent and had retired, before the Keewatin glacier reached its extreme western limit; and that the Keewatin glacier, after covering the Plains region of central Canada for a great length of time, had retired a long distance toward its central gathering ground, before the Labradorean glacier reached its utmost western limit, and that it had shrunk to a very meager representative of its former greatness, when the latter glacier was still of magnificent propositions.

J. BURR TYRRELL.

THE USE OF LOCAL NAMES IN GEOLOGY.

No field of knowledge has ever experienced in the same short period, such a rapid expansion as have the geological sciences in these closing years of the nineteenth century. With this unparalleled advancement of modern geology, occasioned by the changes in fundamental conceptions, and the application of more refined methods of investigation, there has appeared, in every branch, an endless multitude of new and often seemingly useless names. The dropping of the old and familiar terms, the change in meaning of those retained, and the introduction of an unheard-of host of others, has brought forth long and emphatic protests against such innovations.

Many of these protests are not untimely. They come not alone from the layman, but from teachers and specialists. Everyone, who has come in contact with those not specialists, knows that the vast mass of technical terms and the cumbersome verbiage that is everywhere met with in the natural sciences are most disheartening features to the student, and at once raise well-nigh unsurmountable barriers to those who would only be too glad to take up such subjects. To the adoption of an elaborate terminology in any science this phase of the subject presents an obstacle more serious than all others combined.

The whole question is one that cannot be decided by discussion, no matter how able may be the arguments presented on either side. It is not whether the old terms alone are to be used in place of the free and unlimited coinage of new ones at a ratio perhaps of 16 poor ones to 1 good one, but whether from the very nature of the attendant conditions, the adoption of either plan is feasible. It seems not. As long as any branch of science lasts the specialists in that department will continue to introduce new terms to denote new conceptions and to make definitions more precise. In spite of all that others can do,

changes in terminology will go on unabated. Protest is of no avail. A refusal on the part of the general scientific public to understand or to use the new names cannot prevent their adoption. Such action merely sets the majority outside the realm of influence. It is the specialist who sets the pace in nomenclature; others must keep up or drop out entirely. There is no other choice.

Protests against the use of new scientific names are really aimed at the unnecessary terms. In all of these protests there is almost invariably a failure to distinguish between two very different classes of terms. On the one hand the launching of new names is accompanied by a conscientious desire to better the condition of a science by clothing with suitable words the new ideas; on the other hand there is what a recent writer has aptly called a "prevalent and apparently incurable form of mania which busies itself in burdening science with a useless and formidable terminology." The first cannot be too highly commended, nor the second too deeply deplored. To be sure, it is not always possible for one not thoroughly up in a particular department to clearly discern, except in a few cases, the useful or the useless. Time alone can determine. Every progressing science must finally discard all of those titles that have served their purpose. It must also be prepared to receive all of the new ones demanded. Indeed, the rapidity with which a science is advancing is measurable, with but small degree of error, by the number of useful terms that are being proposed.

Much as it is to be deplored, it is nevertheless a fact that the mill from which the large and indifferent grist of new names is continually streaming is not wholly in the hands of those best qualified to manage it. From the very nature of the case there must ever be in its running almost no control. The real factor rendering the mighty host of unfamiliar titles so appalling is that a very large proportion of all of the new names published in the various sciences are proposed by those who are least fitted for the task. The great burden which the literature of a science must carry is the work of amateurs or those who are incapaci-

tated for real scientific work, but fancy that knowledge is advanced, or a new science is founded when they let loose a flood of odd names upon the unoffending world. The inundation is more disastrous in some other departments of science than geology, but among the geological branches it is most apparent, perhaps, in palæontology, where the majority of the names catalogued are spurious.

Fortunately for everybody concerned there is a remedy for the evil that is as divine in its effect as was the discovery of ether in alleviating the physical sufferings of mankind. There is an immutable law that determines the perpetuation of scientific terms, regardless of the quality or of the countless myriads proposed. It is the same law that governs in literature, life and all else — the survival of the fittest. It makes no difference what the new terms are, or where they apply. If they are appropriate, useful and expressive they will last — but not fixed or for all time, only until they have fulfilled their mission, until others more harmonious with the ever-changing conditions take their places. If the proposed titles fail to meet a long felt want they are at once dropped, and forever forgotten. Which, among the new terms proposed, are the really useful ones, the ones destined to survive a while, and which the unnecessary ones doomed to perish at their birth, no man can tell. Moreover, it is absolutely beyond the power of its author, or of any other person, to say which names shall be perpetuated and which shall not. Every new term depends for its life not on the wish of its originator but on its own merit. It goes for what it is worth. With the many others it takes its chances. The final tribunal is the scientific public.

In the application of technical titles neither of the two extremes, too many or too few terms, is desirable. It is not advisable, if the best interests of geological science are to be considered, to adopt by itself either a rigid, unchangeable, and spare system of nomenclature, or one in which there is ponderous verbiage. The proper mean can be reached only after the long and fierce struggle for existence is over. The adoption of

a terminology modeled according to the first extreme, inflex and unchanging, manifestly can never meet the wants of a gr ing science. The establishment of such an arbitrary syst could be defensible only in the case of a dead subject — a c dition that no geologist is willing to admit for his scien Much as simplicity of statement should be sought it is always possible, nor is it always desirable, that it should be lowed at the expense of precision and easy understanding.

On the other hand, a scheme built upon the plan of the s ond extreme is less likely to be tolerated than the first. W is gained in terseness and exactness may be wholly lost in ot directions. The new-born terms become mere symbols, fectly meaningless and useless to all except the author. Th is great danger of producing exactly the opposite effect fr that intended. Instead of a beautiful fabric, the wonder admiration of all, there is merely a lifeless, shapeless m shunned by many, cared for by none.

There is another phase of the question about which ex much confusion. Little mention is ever made of the twof field of usefulness for which every science is designed ; and none is a dual conception more important than in geology. one phase requires a terminology that is technical and spec that is established primarily for the active investigator and is in no way intended to be memorized by the layman or others, or to reach outside of a small and select circle. Th will always exist a need for some such terms and the terms always come in reponse to the need. No amount of protest frighten the specialist out of using them. It may clutter up scientific literature; it may be the bugbear of workers in clos allied branches of science; it may divert the attention of m from the subject itself. No matter. It has come to stay.

The other field demands names that are general, popu simple, and free from technical appearance. The literat thus established is intended for an entirely different class fr that which the first category takes into consideration. This tinction is rarely made, yet no one can doubt the existence

wo wholly different audiences. In the presentation of every liscourse the latter cannot be for both. It must be one or the ther. It is the inalienable right of every author and every ecturer to select his audience. No one wishing to reach the nany would think for a moment, of letting loose on his listeners r readers a flood of absurd and meaningless technicalities ; nor vould a small, selected group of specialists wade through inknown depths of "simple" verbiage.

The coining of new terms to designate new ideas or more pre- ise definitions has a bearing still broader than any yet considered n any of the numerous protests that have been presented. The ayman complains of the host of "long names" with which very branch of science abounds ; the scientist criticises the erminology employed in the various branches other than his wn ; the specialist bemoans the deplorable condition of the omenclature in all branches as well as his own. Now, so far s the question under consideration is concerned, all are on dentically the same plane. When a reason for this is sought nly one stands out permanently. Each critic is, in reality nocking loudly for admission to other departments, without he same hard work and training that he has bestowed upon his wn. Moreover, the protests against the established terminology re all one way ; were they not, the opposite view would not be so otally obscured. The demands for transfer from one department o another is invariably from the more simple and general to the nore complex and special. Why the layman should desire to eave his own field to enter the domains of science unknown to im is as inexplicable as why a stratigraphical geologist should vant to become a geographer or petrographer, or *vice versa*. Seldom does a scientist think of becoming an artisan. Yet if he hould desire to do so, he would be, after five minutes' talk with machinist, carpenter, or electrician, confronted by so many nfamiliar terms — technical terms of every day use — that he vould at once cry out for greater simplicity of language. In he rapidly advancing branch of applied electrical science, for xample, new terms are constantly appearing. The reason that

these technical names are so difficult to understand is that ea is an epitomized history of the special part, its position a function in the complete mechanism.

In the geological sciences the technicalities play the sa rôle as they do in the arts and in business. To the lar majority of people the name Monadnock, for instance, may me only a big building, a war ship, or an Indian, but to the pr fessional geographer it has attached to it a special meaning a single word it sums up the complete life history of a partic lar kind of relief feature—a history that would require t space of a long chapter to describe in "simple" language eve time it is referred to. If such a term chance to be a hap choice, if it save the busy worker the writing of several pag in order to express the same idea in another way, or "if it pro to be acceptable to workers in its field," as its author says, " will take root and flourish ; if not, it will soon wither away a be seen no more."

Granite, trap and greenstone, may be good enough "simpl names to apply to certain rocks, but the terms have become general that in exact work they now mean almost nothing. the petrographer the name pegmatite at once suggests a varie of granite that has a long and intricate history, totally differe from dozens of other kinds of granite, each having a reco equally complicated and equally diverse. This term inc porates in three short syllables history enough to fill a lar volume. But he who wishes to know something about this pa ticular kind of granite called pegmatite, little cares to waste time in going over the whole literature of granite that he m get a little of the desired information. Likewise, who will r say that such a name as websterite, applied to a dark color trap-like rock, does not at once separate the mass from a hu dred other stony aggregates having a similar general appearan and at the same time indicate a whole train of important even that would be otherwise passed over if the more popular nar of trap were used alone. It may be argued that these are use and necessary new names. Yet who could pass judgment

them until after they were proposed? And who can pass judgment on any terms until they are suggested? Or who can say whether they would be useful or not until they are tried?

In this day and age the geological sciences are protected at the start by one great safeguard against the promiscuous introduction of new names. There is one test that every new name must stand before it can venture to ask for recognition. This is the test of definition. Every new name in geology must be properly defined before it can be noticed at all. Its subsequent career depends upon its utility.

It has been already intimated that the rate with which a science is advancing is measurable by the number of new and useful terms that appear. At present this statement is especially true of some of the geological sciences. To be sure, new terminology does not necessarily indicate new facts, but when new terms receive the favor of those best qualified to pass judgment upon them, of the specialists in the particular department, when also these names stand for new conceptions, the branch of knowledge thus affected is certainly undergoing such radical change that the final outcome must be essentially very different from the old. This rapid change in terminology is at present characteristic of several of the branches of geology.

In no department has the coining of new names gone on more vigorously than in stratigraphical geology. The reason is to be found partly in the inherent conditions existing in this field, and partly in the complete change of base that this branch of the science has undergone in late years. The fundamental conception of the geological formation, whether large or small, whether a single bed or a great series, is a sharply defined "geological unit," instead of a vaguely bounded "group" of layers. The former is now capable of being clearly demarcated by strictly physical characters, that are the direct outgrowths of the actual conditions giving rise to the formations themselves; the latter is too often based upon trivial or accidental characters which are

relatively unimportant as critical criteria, either in classification or correlation.

The principle underlying the recent naming of geological formations gives to each stratigraphical unit a special geographic designation, derived from some prominent town, watercourse or land form, within the boundaries of that formation. As thus established the latter is a well-defined and independent unit, having a definite place in the general geological scheme, no matter how this may change afterward, or what method of classification may be followed. This definite stratigraphical unit contrasts strangely with the unwieldy, ill-defined and usually little understood large formation of the past, the very name of which indicated either lack of exact knowledge of it itself, or a covering up of ignorance regarding its affinities. By this new method, or if it be more exact, by the vigorous application of an old principle that was so loosely followed as to be almost unrecognizable, geological nomenclature has been certainly greatly increased, even enormously enlarged by the introduction of the new plan. The former list of names numbered only about two score, indicating all of the smallest subdivisions which went to make up the general geological column. The names of the new list run up into the hundreds and even thousands, are different in every considerable area, and additions are constantly being made.

It is against this copious multiplication of geological names that the protests have been chiefly made. Curiously enough the struggle has been reduced to a clash between the practical field geologist on the one hand, and on the other the laboratory worker, those especially interested in the other departments than stratigraphy and the palæontologists, who see their standard classification abandoned, and their usefulness in the domains of geology diminished. And the former have won.

When, a decade and a half ago, various geological surveys in this country were established or reorganized, those entrusted with the work soon found that, if speedy and exact results were to be secured, and if substantial data were to be obtained upon which all other workers could also build, something else must

e devised than the existing scheme of vaguely defined geolog-al formations, having no comparable limits in different prov-ces and even diverse values in different parts of the same rovince. A natural, yet elastic foundation must be secured. ractical experience and the demands of the times quickly ointed out a suitable plan. So well has it served the purpose nd so readily adaptable is it to the varying conditions met ith on all sides, and the unforeseen exigencies constantly aris-g, that it has brought under its standard nearly every practical eld geologist.

The method of designating geological formations by geo-raphical names certainly does greatly increase the nomencla-ire, at times seemingly to a burdensome extent. This appears be the only objection that has been yet urged against it that ight call for notice. Yet, to all, except those who do not care go beyond the ordinary text-book in geological work, even is seems hardly necessary, since it is offset by so many man-est advantages.

It may be truly said that no greater boon to the working eologist has been yet devised, than the plan of designating, eographically, geological units irrespective of exact position or ge. Incorporated in the new plan are all the salient good fea-ires of the old method, while none of the objectional ones are etained. Since its adoption a vast mass of valuable information as been obtained that was previously unthought of, information iat is in a shape to be always used, without the necessity of the ser personally going all over the ground again; the other depart-ients of geology have been greatly aided; and stratigraphical eology itself has made greater real progress in the short decade iat has elapsed since the method with its new impetus came ito general use than in all time previous. In the same short eriod more has been learned about the nature of sedimentation, ie actual relations existing between rock formations, and the tructure of the lithosphere than was possible before. In fact a ational physical basis for geological correlation and classifica-ion has been found.

The real meaning, then, of the multitude of new names that has recently made its appearance in the literature of stratigraphy, is the practical adoption of more refined methods of geological work, the provision of suitable means for the collection of more exact geological data, and the grasping of more advanced and rational conceptions regarding geological correlation and classification.

CHARLES R. KEYES.

'HE WEATHERED ZONE (SANGAMON) BETWEEN THE IOWAN LOESS AND ILLINOIAN TILL SHEET.

PRELIMINARY STATEMENT.

Extent of Illinoian till sheet.—The Illinoian till sheet here iscussed was formed by the Illinois glacial lobe in connection ith the maximum extension of that lobe. It seems quite well stablished that a lobe on the east, which covered southeastern ndiana and southwestern Ohio and extended a short distance nto Kentucky also had its culmination at the Illinonian stage of laciation. Farther east the Wisconsin sheet in many places eaches the glacial boundary, but there are small tracts of drift lder than the Wisconsin, lying outside its limits in eastern)hio, northwestern and northeastern Pennsylvania, and northern Iew Jersey, which may prove to be of Illinoian age, though his is as yet not established. To the west of the Illinois glacial obe there is a large area covering northern Missouri, southern owa, northeastern Kansas and eastern Nebraska, in which the pper sheet of till is older than the Illinoian, and is now referred o the Kansan stage of glaciation. The lobe which formed it is ere referred to as the western lobe, for it has as yet received no nore definite name. The Illinoian sheet has not been recog- ized farther west than the limits of the Illinois glacial lobe. It eems probable, however, that it may be found in the western egion, and possibly it occurs as far south as northern Iowa.

The Illinois glacial lobe at its maximum extension to the outhwest, crossed the Mississippi and encroached a few miles n Iowa, in the district between Clinton and Ft. Madison. But arther north and south it appears to have terminated east of the Iississippi, except, perhaps, for a few miles near St. Louis, Mo. 'he southern border of this lobe apparently reached to the gla- ial boundary from St. Louis eastward as indicated above. It is

the southwestern border which claims our attention at this ti
since the Illinois lobe there overrode to some extent the sl
of Kansan drift, formed by the western lobe which covered m
of Iowa and portions of the neighboring states.

The southwestern limits of the Illinoian drift is usually mar
by a definite marginal ridge or by chains of knolly and sligl
ridged drift. Beginning at the south, in Jersey county, Il
few miles north of St. Louis, and tracing northward, the mar
is found to follow the east side of the Illinois River in Jer
and Greene counties, and to carry only occasional knolls and
ridges. It crosses the Illinois in southeastern Pike county
takes a northwest course, coming to the Mississippi bluff n
the line of Pike and Adams counties. It there enters a dist
which had been covered by the western lobe at the Kansan in
sion. The Illinoian border takes a northward course along
near the east bluff of the Mississippi through Adams and H
cock counties. A definite ridge twenty to forty feet high is dev
oped along much of the Illinoian margin in Pike and Ada
counties, and as far north in Hancock county as a point oppo
Keokuk, Iowa. For a few miles above Keokuk the Mississi
River apparently follows nearly the border of the Illinoian
sheet, and no definite ridges are found. At the bend of
Mississippi below Ft. Madison the Illinoian border crosses i
Iowa. Its marginal ridge can be traced without difficulty fr
the vicinity of the Mississippi River bluff south of West Poi
Iowa, northward through Lee, southeastern Henry, northweste
Des Moines and western Louisa counties to the Iowa River
Columbus Junction. Its course there changes to the northea
and it can be traced diagonally across Muscatine county from
southwest to its northeast corner. It has been traced no fartl
to the northeast because of concealment by a heavy sheet
loess which borders the Iowan till in Scott county, Iowa. It
known to extend as far north as Scott county, for the Illin
till sheet has been observed in southern Scott county as far e
as Davenport. The concealment by the Iowan loess is ve
great, not only in Scott county, Iowa, but also in Rock Islan

Whiteside and Carroll counties, Ill. It becomes a difficult matter, therefore, to decide upon the position of the margin of the Illinoian drift in any of these counties. It is also not fully decided whether it reaches to the border of the driftless area in Jo Daviess and northwestern Carroll counties, Ill , and in southwestern Wisconsin. The balance of probabilities, however, seems to favor its extending to the driftless area.

The Illinoian till sheet overlaps a few miles the Kansan till sheet of the western lobe from the latitude of Hannibal, Mo., northward to the vicinity of the southern point of the driftless area. In this region of overlap a weathered zone is developed between the Illinoian and Kansan till sheets at the level of the outlying Kansan surface as indicated below.

Introduction of the name Illinoian.—The tracing of this southwestern border of the Illinois lobe was begun by the writer in the autumn of 1892, and carried as far north as Hancock county, Ill., that season. No opportunity to continue the study was afforded until the spring of 1894, when the mapping of the border was carried from Lee county, Iowa, northward to Scott county. The greater part of the data presented in this paper, and conclusive evidence of a long interval between the deposition of the till sheets now known as the Kansan and Illinoian, and also the evidence that the Illinoian is much older than the Iowan had been obtained as early as June 1894. The writer then began to use the name Illinoian in correspondence, but it seemed best to defer its introduction into literature until opportunity had been afforded other geologists to examine it. In August 1896 Professor T. C. Chamberlin and Dr. H. F. Bain were conducted by the writer to some of the exposures in southeastern Iowa which show the soil above and below the sheet formed by the Illinois lobe, and each recognized the need for a distinctive name for this drift sheet. The name was accordingly soon introduced into geological literature by Professor Chamberlin.[1]

Other interpretations.—At the ninth annual meeting of the Iowa

[1] See editorial JOUR. GEOL., October–November 1896, pp. 872–876.

Academy, held December 1894, Mr. F. M. Fultz read a paper[1] in which the interpretation was presented that the ice lobes alternated in the occupancy of the district south of the driftless area, and that the latest occupancy was by the western lobe. The extension of the eastern lobe into Iowa had been inferred by him through the discovery of a bowlder of red jasper conglomerate near Augusta, Iowa, which was apparently brought from north of Lake Huron. The evidence of an extension of the western lobe over the same district was found in eastward-bearing striæ along the brow of the Mississippi bluff at points farther east than the site of this bowlder. Mr. Fultz argued that if the striæ are not the product of the latest invasion they would not have been preserved in such an exposed situation. He also referred to some bowlder strewn terraces in the Mississippi valley at and above Keokuk as moraines, and correlated them with the striæ as the product of the last ice invasion. The following summer Mr. Fultz and the writer, while examining some rock outcrops in Burlington, found a striated surface in which the bearing is westward. This was evidently produced by the Illinois lobe, and as it is in a section about as exposed to obliteration by a subsequent invasion as those cited by Mr. Fultz in his paper it became necessary to readjust the views set forth in that paper. This was done at the tenth meeting of the Academy in December 1895, and the question of the relation of the two invasions was there left somewhat in doubt.[2] The bowldery terrace interpreted by Mr. Fultz to be a terminal moraine has been examined by Professor T. C. Chamberlin and Dr. H. F. Bain, as well as by myself, and to each of us it seems best explained as a residue of coarse material formed by a stream excavation along the Mississippi valley subsequent to the later ice invasion. The evidence that the Illinois lobe was last on this ground seems conclusively shown in the relation of its till sheet to that of the sheet formed by the western lobe. The latter can be traced under the Illinoian sheet as indicated below. In addition

[1] Proc. Iowa Acad. of Sciences, Vol. II, 1895, pp. 209–212.

[2] *Ibid.*, Vol. III, 1896, pp. 60–62.

to this evidence there is found an abandoned river channel in the district immediately west of the limits of the Illinoian drift which carried southward the drainage outside the Illinois ice lobe. The banks of this channel are well defined, and the channel evidently has not been filled by the drift of any subsequent invasion.

Extent of the Iowan loess.—By the term Iowan loess is meant that sheet of loess which connects at the north with the Iowan till sheet. A till sheet of Iowan age has been found in northern Illinois as well as in eastern Iowa and it probably covers the greater part of the northern half of Illinois. It is, however, covered by the Wisconsin till sheet from Bureau county, Illinois, east and south. How much of Indiana and Ohio was covered by the Iowan ice invasion has not been determined. The Iowan till certainly does not extend as far south as the Wisconsin in those states. The loess forms a heavy deposit along the border of the Mississippi and Illinois valleys, but is comparatively thin in the region east of the Illinois, its average thickness being scarcely ten feet. A silt tentatively correlated with the loess covers the Illinoian till sheet wherever exposed outside the Wisconsin from the Illinois River eastward to central Ohio. The Sangamon weathered zone between the loess and the Illinoian till sheet is found from central Ohio westward to southeastern Iowa, *i. e.*, to the limits of the Illinoian till sheet. The Iowan loess extends also over the Kansan till sheet of southern Iowa and adjacent portions of Missouri, Kansas and Nebraska, but this loess is separated from the underlying till by a much longer interval than that between the loess and the Illinoian till sheet, an interval comprising two interglacial stages and one glacial stage.

Application of Buchanan.—At the tenth annual meeting of the Iowa Academy Professor Samuel Calvin, after describing certain gravel deposits in northeastern Iowa, introduced the term Buchanan as a name for an interglacial stage following the Kansan,[1] and made the following statement concerning the origin and age of the deposits:

[1] Proc. Iowa Acad. of Sciences, Vol. III, 1896, pp. 56-60.

As to their origin the Buchanan gravels are made up of materials derived from the Kansan drift. As to age they must have been laid down in a body of water immediately behind the retreating edge of the Kansan ice.

Manifestly the deposition of the Buchanan gravels covers but a small part of the time between the Kansan retreat and the Iowan advance. Unless therefore the deposition and subsequent weathering both be included under this name it does not fill an interglacial stage. Were there no Illinoian glacial stage to break the continuity of interglacial conditions from the Kansan to the Iowan stage of glaciation it would not seem necessary to look for other terms. But in view of this glacial interruption there seems need for names which will stand for the weathered zones above and below the Illinoian till sheet. It is for this reason that the name Sangamon is here suggested for a weathered zone separating the Illinoian till from the overlying loess. In an accompanying paper the name Yarmouth is introduced for the weathered zone between the Illinoian and Kansan till sheets. The name Buchanan may still have the significance given it by Professor Calvin; and if weathering be included may perhaps be used to cover the time involved in the two interglacial stages with the intervening glacial stage.

THE SANGAMON WEATHERED ZONE.

Earliest recognition.—Apparently the first recognition of the occurrence of a definite soil horizon between the Iowan loess and the Illinoian till sheet is that reported by Professor A. H. Worthen, in the Geology of Illinois.[1] In his report on Sangamon county, Illinois, made in 1873, Professor Worthen called attention to a soil found at the base of the loess in Sangamon and neighboring counties. The soil apparently was first noted by Mr. Joseph Mitchell, in the excavation of wells in the northwest part of the county and in neighboring portions of Menard county. Mr. Mitchell furnished for publication in the Geology of Illinois the following section of the beds usually penetrated.

[1] Geol. of Illinois, Vol. V, 1873, pp. 306-319.

	Feet
Soil,	1 to 2½
Yellow clay,	3
Whitish jointed clay with shells,	5 to 8
Black muck with fragments of wood,	3 to 8
Bluish colored bowlder clay,	8 to 10
Gray hardpan — very hard,	2
Soft blue clay without bowlders,	20 to 40

Professor Worthen states that the bed overlying the black muck is undoubtedly loess, also that the black muck indicates conditions suitable for the growth of arboreal vegetation in the interval between the deposition of the bowlder clay and the overlying loess. The name Sangamon is taken from this locality where the soil was first reported.

General prevalence of a weathered zone at the base of the Iowan loess.—In the locality just mentioned there appears to be only a bed of muck to indicate the interval between the deposition of the bowlder clay and that of the overlying loess, for the clay immediately below the muck is described as of a blue color, a feature which suggests that there was not much oxidation and leaching, or else that there was subsequent deoxidization. The more common phase is a reddish brown till surface for which Dr. H. F. Bain has proposed the Italian name "ferretto,"[1] which may or may not be accompanied by a black soil. This reddish-brown surface appears to have been developed in all places where there was fairly good drainage. But in places where the drainage was imperfect a black muck of considerable depth accumulated and the reddened zone was imperfectly or not at all developed. In western Illinois the exposures of a black soil at the base of the loess are relatively few, but the reddened till surface is a common feature in every township. In much of the white clay district of southern Illinois and in portions of the Sangamon drainage basin a black soil is well developed. It is also well developed in southeastern Iowa. Where the black soil is best developed leaching is found to have extended in places only one to two feet into the underlying till but it often extends to a depth of

[1] See Proc. Iowa Acad. of Sciences, Vol. V, 1898 (in press).

six feet or more. Where it is absent the leaching generally extends to a depth of six feet below the base of the loess. The variations in depth of leaching appear to depend on the conditions for percolation of water, being greatest where percolation is most rapid.

Noteworthy exposures of Sangamon soil.— A few instances of the exposures of this soil are selected which will illustrate the variability in its character. The first section, at Ashland, Ill., is near the place where Professor Worthen reported its occurrence.

The following series of drift beds were penetrated by a coal shaft at Ashland, the identifications being made by the writer from samples of the material preserved at the engine house:

	Feet
Soil,	1½
Yellow loess, fossiliferous,	9
Blue loess,	2
Peat with black, sandy slush,	22
Bluish, gummy clay with few pebbles,	20
Yellow till,	30
Total drift,	84½

At the air shaft sand was found in the place of the blue gummy clay beneath the peaty slush. A similar thick bed of peat has been noted at several other points in that region, one of the most conspicuous being in a well at Virginia City made by Mr. Oldridge. The peat was entered at the base of the loess at about 15 feet and continued to a depth of 28 feet, beneath which a blue gummy clay was found. The drift at Virginia City has a depth of 187 feet, as shown by the coal shaft. This shaft is reported to have passed through a lower black soil between till sheets at 67 to 70 feet.

In the south part of the Sangamon basin, in the vicinity of Taylorville, Ill., the loess which has a thickness of 10 to 15 feet is underlaid by beds of sand and gravel, carrying thin peat beds in their midst as well as at the junction of the loess and the sand. At the Taylorville coal shaft the uppermost peat bed was found at 13 to 15 feet, and the lowest at 40 to 44 feet. Numer-

ous exposures of this peaty material alternating with sand beds may be seen in ravines in that vicinity.

In October 1896, Professor Chamberlin and the writer examined together numerous exposures of the Sangamon soil in the portion of eastern Illinois south of the limits of the Wisconsin drift, chiefly in Cumberland, Coles, and Shelby counties. North of Greenup there are exposures where the subsoil beneath the Sangamon soil is traversed by branching rootlike tubes one to two inches in diameter, which were easily traced ten to twelve inches below the soil proper. These tubes are filled with the black soil which apparently settled into them upon the decay of tree roots. There seems to us little question that the Sangamon soil here supported a forest. The till below this soil in these counties shows leaching to a depth of several feet. It also presents weathered cracks and seams extending down a depth of 20 feet or more. Similar leaching and weathering below the Sangamon soil has been observed by the writer in several other counties in southeastern Illinois, and in Vigo, Clay, and Sullivan counties in southwestern Indiana, thus extending it to the southeast border of the Illinois lobe.

Returning to western Illinois, excellent exposures of black soil and leached subsoil are found along the Santa Fé railway in eastern Knox county. The soil may be seen distinctly at a distance of nearly one-fourth mile. It is of a deep black color, resembling the surface muck found in flat portions of the uplands. The till beneath it has been leached to a depth of about four feet. The loess has a thickness of 12 feet, and is slightly calcareous in the lower portion. The entire leaching of the till may confidently be referred to a date earlier than the loess deposition.

At Galva, Ill., a black soil at the base of the loess is well exposed in a clay pit at the brick yards east of the city. A large log was found imbedded in this soil, which here has a depth of two feet. The overlying loess is 15 feet in depth. A well at the brick yards penetrated 40 feet of till below the buried soil, of which the upper 30 feet has a yellow color and the remainder a blue-gray color.

In southwestern Carroll county, Illinois, there are extensive exposures of a soil at the base of the loess, made by the Chicago, Burlington and Northern Railway Company, the loess having been removed to make a fill across the valley of Johnson Creek. Probably a half acre of the buried soil is here exposed to view. It has a deep black color to a depth of 10 or 12 inches, beneath which it assumes a greenish yellow color, such as is presented by subsoils beneath poorly drained regions. This subsoil is leached as far down as exposed, a depth of three feet. This locality was visited last November by Professors Calvin, Udden, Bain, and myself, and each recognized the clear indications of a long interval prior to the loess deposition. It may be noted in this connection that Judge James Shaw mentioned a soil in Carroll county in his report on the Geology of Illinois, which apparently has the same horizon as the one just described. It was found at a depth of 15 feet and a deposit of wood two or three feet in thickness was associated with it.[1]

On the portion of the Illinoian sheet in southeastern Iowa many excellent exposures of the Sangamon soil are found. An exposure similar to that in Carroll county, Illinois, has been made at West Point, Iowa, where the Chicago, Ft. Madison and Des Moines Railway Company has excavated to obtain filling for its tracks. The loess has been removed over an area several rods square, leaving the buried soil at the base of the excavation. Although the exposure is on the crest of the ridge which marks the western limits of the Illinoian drift, the soil is of a deep black color and has a depth of several inches. This exposure was visited by Professor Chamberlin, Dr. Bain, and myself in August 1896, as were also several roadside exposures between West Point and Denmark, and between Denmark and Ft. Madison.

Exposures in other portions of southeastern Iowa are given in connection with the discussion of the Yarmouth weathered zone.

Valley excavation during the Sangamon interglacial stage.—The large streams in western Illinois and southeastern Iowa are

[1] Geology of Illinois, Vol. V, p. 80.

characterized by high-level terraces. The valleys of which these terraces are the bottoms have been formed in the Illinoian till sheet, and are covered by the Iowan loess. The excavation may, therefore, be referred to the Sangamon interglacial stage. They are broad and very shallow. On Skunk River, along the borders of Lee and Des Moines counties, Iowa, the terrace is only 30 to 40 feet below the level of the uplands, but the valley is nearly two miles in average breadth. The valley cut below the level of the terrace is more than 100 feet in depth, but is only one-half mile in average breadth. These features indicate that during the Sangamon interglacial stage the stream had a lower gradient than at subsequent stages. On the neighboring portion of the Mississippi the valley formed at the Sangamon stage was shallow, as on Skunk River, but was not much wider than the inner valley. The large volume of water flowing through the valley at the time when it constituted an outlet for the glacial Lake Agassiz and the glacial lake in the Superior basin is perhaps the cause for the relatively great erosion subsequent to the Sangamon interglacial stage.

In southern Illinois and southwestern Indiana the main streams usually flow in broad shallow valleys, in some cases several miles in width, which were apparently built up by the glacial and fluvio-glacial deposits of Illinoian age. It is seldom that sufficient deepening of streams has occurred to produce well-defined terraces; and it is not an easy matter to determine the amount of work accomplished during the Sangamon interglacial stage. On the borders of these lowlands the Iowan loess rises above the level of the modern streams and at such places occasional exposures were found in which the junction of Iowan loess and the Illinoian till is marked by a thin bed of material more pebbly than the typical till; a feature which is thought to indicate moderate stream action prior to the deposition of the loess. A similar feature has been noted on the borders of many of the small valleys in western Illinois and southeastern Iowa.

FRANK LEVERETT.

STUDIES IN THE DRIFTLESS REGION OF WISCONSIN II.[1]

SINCE my article which appeared in the November-December number of the JOURNAL OF GEOLOGY was written, much additional evidence has accumulated, largely along new and supplementary lines. There have, however, been some additions along the lines there developed, which I beg to notice in an extended footnote.[2]

[1] On page 834 of my last article a change in the paragraphing somewhat obscured the course of the reasoning. The objections to torrential action were grouped under three heads: *a*, transverse ridges, beginning at the tenth line from the top; *b*, the lateral ridges; *c*, the size of the material.

The first head was improperly made to begin at the twenty-third line from the top, where there is only a reference to the ridge, *b*, Fig. 1. I think that I was myself partly the occasion of the mistake, since the *b* stood alone, Fig. 1 having been omitted. The third head should have been worded more in harmony with the others and more indicative of its own character.

[2] Regarding the ridge *d* (Fig. 1 of last article) I stated that it seems to belong structurally to both valleys. But the heavy masses of ferruginous sandstone which form so conspicuous a component of the ridge appear to be peculiar to the east valley. The knob *d* (Fig. 1) is composed of it. It also occurs on the north rim at *c* (Fig. 7). Although much harder than the sandstone in the same horizon on either side, it is not as prominent in the topography as we should have expected, owing probably to the fact that it has pronounced joint structure and the separate masses are rather easily dislodged. The supposed bowlder bed on the west side of the west valley (shown in gully) is of small material, undoubtedly a water deposit, leaving the ridge *b* (Fig. 1) as the terminal deposit for that valley.

An interesting feature has developed in connection with the ridge shown in Sec. 4, Fig. 2 of last article, occurring in the third valley described (position shown at *c*, Fig. 4). A well dug just in front of the line of the section struck at once into a clay resembling the loess and entirely free from stones. It continued in this for its entire depth, about twenty feet.

The terminal arrangements of the material in the last valley described (partly shown in Sec. 6, Fig. 2) displays a certain feature which claims further notice; an independence of the minor features of the topography, shown in the direction of movement and the disposition of the beds. In the accompanying figure I have represented by contour lines the original rock surface and by dots the contour of the lower end of the beds. The axis of the old valley runs very close under the eastern hill, while on the west a broad shelf rises gradually toward the nearest bluff.

Distribution of transported material on the higher slopes.—Most of the deposits previously described fall between the horizon of the present river-level and that of the highest terrace, so that although there seems to be excellent reason on other grounds

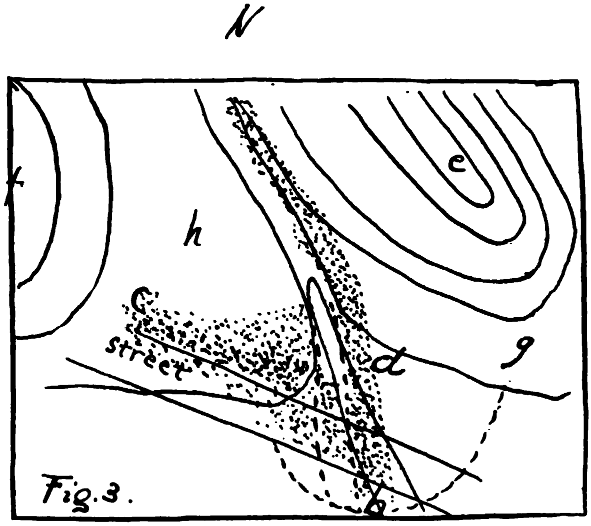


FIG. 3. Scale 300′ to an inch. Adapted from the village plat, which I used as the foundation.[1]

f. End of a short spur or projecting angle of one of the higher bluffs.

e. End of a long spur forming the northeast valley rim.

g, h. Rock shelves sloping gently from their adjacent hills.

ab. The bowlder ridge, the south end of which lies over the old rock valley, shown in entire lines, while the present drainage indicated by dotted lines runs further west just inside of the ridge. It has both an outward and an inward slope plainly apparent in spite of the loess, which, however, as the street cutting shows, greatly exaggerates its apparent breadth and diminishes its apparent height. The bowlder bed doubtless covers all of the shelf *h*, but being heavily covered with loess I have only indicated that part which is uncovered. On its south front it declines from a thickness of about twelve feet or fifteen feet to nothing in the width of a street.

The asymmetry of the deposits, *i. e.*, their presence on one side of a valley, and apparent absence on the other has been something of a difficulty in working out the

[1] These maps have necessarily been constructed without the aid of special measurements. But while they must needs lack the exactness which such a method would have given, they have been carefully constructed from fairly correct data, and after thorough study of the topography, and are essentially correct. The valley bottoms, however, offer especial difficulties, since the series of deposits of which the loess is the top, has been eroded so as to form a most intricate system of ravines of which only the principal ones could be represented.

for disputing the competency of running water, landslides or creep to give rise to such deposits, it cannot be denied that they lie within the horizon where such agents are operative. It is, therefore, very desirable to trace the deposits into higher levels. But the middle portions in all the valleys are so deeply covered by the loess — which has a strong tendency to fill up depressions and obliterate minor irregularities of surface — that nothing can be seen save in the rare cases in which gullies are deep enough to slightly expose the structure, and even these, although affording valuable evidence as to the sequence of the deposits, etc., give no decisive indication as to their character.

On the outlying secondary hills the loess is not so thick, and a systematic study of these has given unexpectedly interesting results. The accumulations there, unlike those of lower levels in which all the different local formations are represented, are composed almost exclusively of limestone from the tops of the

glacial hypothesis. But as shown above, while on one side the deposit may rest on a shelf, on the other it may lie in the axis of a valley, where if circumstances are favorable it may be covered by late deposits. This asymmetry is, however, quite as serious an objection to torrential action or to the flow of semiliquid material, neither of which could form deposits at a notably higher level on one side of a valley than on the other. At *c* the bowlder bed rises into a sharp ridge three or four feet high as shown in Sec 6, Fig. 2 (previous article). From *c* to *d* there is a nearly uniform eastward slope, broken only by the present drainage channel. Had there been nothing in the configuration of the ridge to confine the drainage it must have left the bowlder bed near *d*, to enter the lower level extending southeastward from thence. The dotted half circle drawn through points of approximately equal elevation on either side of the old drainage channel will show how widely the bowlder deposit departs from the normal plane of a water borne deposit.

There is an implied suggestion in Professor Chamberlin's note prefacing my first article, which requires more specific notice than I have yet given it. It is whether these deposits might not have resulted from landslides or from the lavalike flow of saturated earth during thaws, or the more gradual creep due to repeated thawing and freezing. Perhaps the best answer will be to state the conditions presented by a single case. The deposit shown in Sec. 3 (Fig. 2) of last article lies on a rock shelf and reaches to about forty feet above low water of the Mississippi, a height which is not reached in the valley for several hundred feet back. A 2° slope would not intersect the bottom of the valley at a distance much, if any, short of 1500 feet. To reach its present position from any possible source the material would have had to travel about 3000 feet and make a sharp bend in its course. Its probable source was one of the bluffs shown in Figs. 4 and 5, present article. Limestone is abundant in the deposit, and some of the fragments quite large.

higher bluffs. To this is added a comparatively small percentage of material from the transition beds at the base of the limestone.

Circs.—Short, direct valleys, with broad heads and narrow outlets, are finely shown in this vicinity. The deposits found in

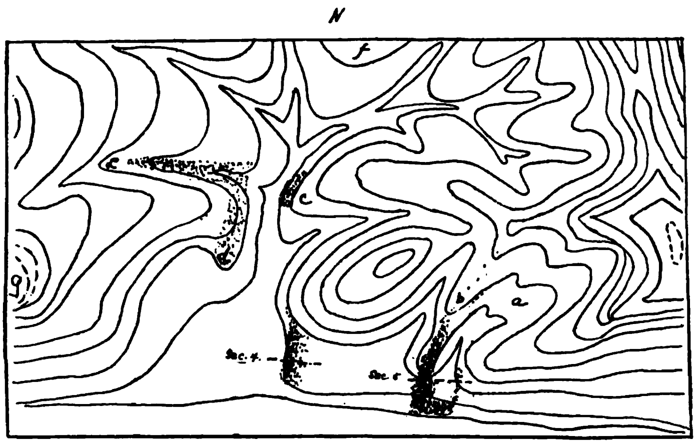


FIG. 4. Contour sketch map in which the center is occupied by the lower end of a large valley—the third in the series described. At the extreme right is a bluff, the highest and most massive in the group. Descending from this is the small valley or circ, *a*, the fourth described. The positions of Sects. 4 and 5 (Fig. 2) of the previous article are indicated. The bowlder deposits shown in Sec. 5 continue along up the crest of the ridge *b*, as shown by dots. I have endeavored by the greater or less concentration of the dots to indicate the relative abundance of the bowlder deposits. Sec. 4 (Fig. 2) was obtained at the point *c*. The peculiar point *d* appears to be largely or wholly composed of similar deposits. In the ravine, *e*, extensive washouts reveal very thick bowlder deposits. Doubtless similar deposits occur in the other ravines within the secondary hills, but the conditions are not favorable for observation. The lower end of the bowlder covered spur shown in Fig. 4 is seen at *f*. West of the middle of the valley, no hills reach the limestone horizon, save that at *g*. Scale 1000′ to an inch. Contour lines at intervals of 50′.

In this and the following maps I have indicated the base of the limestone horizon by heavier contour lines.

connection with them show several marked variations in detail from those found in the larger valleys, while they have a close resemblance among themselves. They all front on the Mississippi and are the result of the comparatively rapid erosion which its presence induces. The secondary hills which separate neigh-

boring circs are very wide at the outer margins, but narrow to ridges of only a few feet in width at the points where they join the primary bluffs. In some cases these connecting ridges have been so

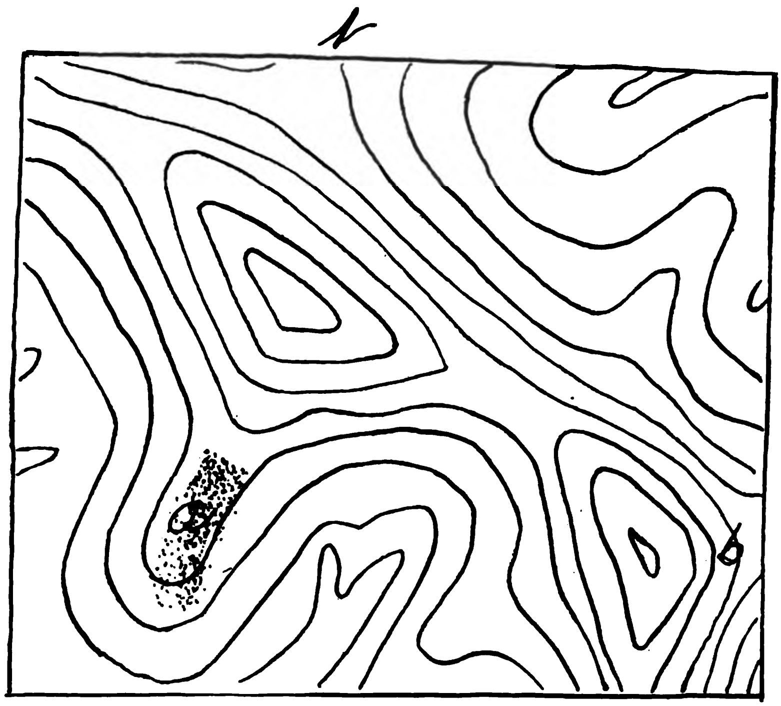


FIG. 5.—Sketch map of a portion of the same valley as shown in Fig. 4, joining that on the north—(east end). It shows a spur extending out from one of the angles of a limestone-covered bluff and having its top covered with limestone débris. It appears to extend downward somewhat on the east side, but, on account of the increasing thickness of the loess, it cannot be told how far. At *b* a spur of very similar height and form holds almost identical relations to its primary bluff, but it is entirely destitute of limestone débris. It is evident, therefore, that one has been subject to the action of some agent which did not effect the other. Scale 500′ to an inch. Contour lines at intervals of 50′.

worn away as to form a considerable sag. For convenience, I will speak of these secondary hills between circs as buttresses.

For the purpose of illustration I have selected one of the finest of these, which is shown in contour lines in the accom-

nying sketch map, Fig. 6, together with portions of the circs joining on either side. A portion of the main bluff, with its nestone cap, is shown in the upper right-hand corner (in order

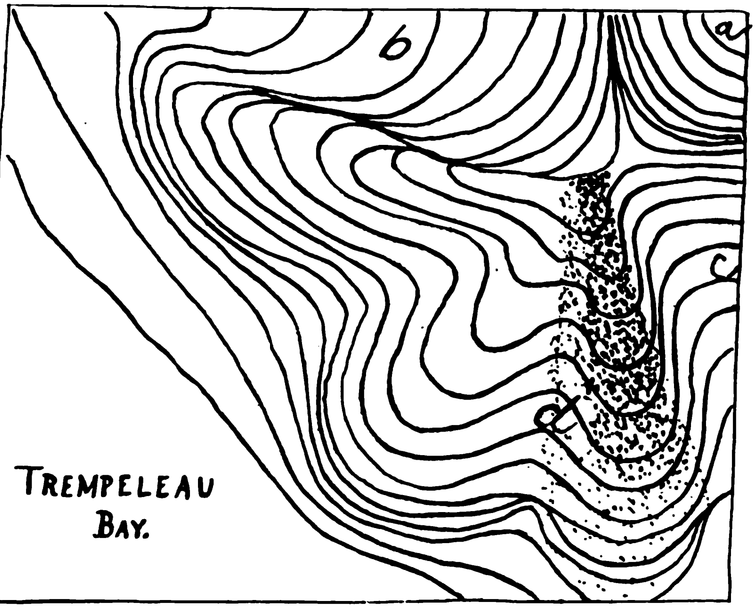


FIG. 6. Contour sketch map of a single buttress with a portion of its primary ff, *a*, to illustrate the distribution of the limestone débris as shown in connection h the circs. Parts of two circs are shown, *b* and *c*.

The dotted portion shows where the limestone débris occurs. I have endeavored show its relative abundance by the concentration of the dots. It should be observed, wever, that while on the side furthest from the circ it is really represented by only ttered fragments, in the thickest part next the circ it is piled up to a thickness parently of several feet. The side of the buttress toward the circ *c* is steep but not cipitous, but that toward *b* is a vertical escarpment several hundred feet long, and enty to fifty feet high.

Scale 400′ to an inch. Contour lines at intervals of 25′.

be more easily distinguished by the eye, the base of the lime- one is represented by heavier contour lines). The dotted area the east side of the buttress shows the portion covered by ansported limestone. It is most abundant immediately adjoin- g a circ, diminishing as we recede from that, but not entirely

ceasing until we have passed the bottom of the nearest ravine (*d*, Fig. 6). When it occurs on both sides of a buttress, and there is but a single intermediate ravine, it extends in some degree over all parts. The maximum thickness of these accumu lations is nowhere shown in section. Such indications as I have noted lead me to the belief that it will probably not exceed six feet or seven feet, thinning off until it is represented by scattered bowlders only. There is often an appearance as though the material had been thrown into subordinate ridges of low relief. They are too faint, however, to be relied upon as evidence, unless their reality can be confirmed by sections. The fragments range from massive or tabular forms several feet across down through all grades, and they lie as close together as the fragments in a macadamized road. The slopes from the circs to the bounding buttresses are nearly always steep (35° to 40°). That overlooking the circ *b* (Fig. 6) is vertical for heights varying from twenty to fifty feet. The small valley shown at *a*, Fig. 4 has somewhat the character of a circ. The sharp ridge which forms its western rim, or buttress, has a train of limestone débris for the greater part of its length, sometimes rather straggling, but quite abundant on its knoblike outer end, and the terminal slope, at the bottom of which it connects with the ridge shown in Sec. 5, Fig. 2 (previous article).

The larger valleys.—Of the occurrences in the larger valleys two examples are here sketched. The first, Fig. 5, is found in the largest of the valleys (the third described in previous article). The highest portion of its rim lies toward the northeast (compare Fig. 4), and a portion of this, a peak of triangular form, is shown in the figure. The northwest-southwest portion is a part of the valley rim, while the spur, *a*, projects into the valley. The top of this spur is thickly covered with limestone débris, save the inner end, and the slope of the main bluff up to the base of the limestone, where it is lacking. Whether the deposit on the spur is continued eastward and southward into the valley cannot be told on account of the loess. The second example, shown in Fig. 7, occurs in the easternmost of the two

onfluent valleys first described, in which the highest portion of
ıe rim is toward the northwest, and consists of a high and
ther long bluff, somewhat crescentic in form. The north rim
f the valley consists of a much lower ridge, nowhere reaching

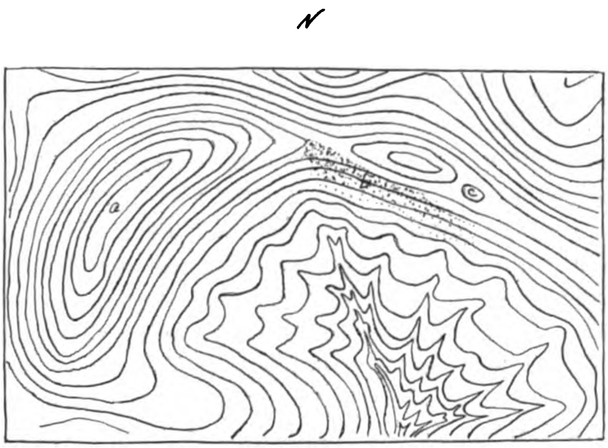


FIG. 7. Contour sketch map of the easternmost of the two confluent valleys first scribed in the last article. (The lower part is shown in Fig. 1.) The enclosing rim the valley reaches the limestone horizon at only two points. One of these is the ıg bluff, *a*. The other would fall a couple of inches outside of the lower right-hand rner and is the same as the one shown at *g*, Fig. 4. At *b* occurs the train of lime- one débris. Its downward extension is concealed by loess. *c*, knob of hard, ferru- ıous sandstone.

Scale 800′ to an inch. Contour lines at intervals of 25′.

the horizon of the limestone. In proceeding eastward from ıe base of the limestone at the northeast end of the high bluff, mestone débris is lacking for some three or four hundred feet. then appears suddenly on the top of the ridge, extending to ı unascertained distance downward on the inside. A little fur- ıer eastward the upper edge of the débris begins to fall a little ıort of the top of the ridge (on the inner side), and from that oint it continues to decline at a nearly uniform rate, making an ıgle of about 4° or 5° with the horizon. The limestone is in ıfficient abundance to wholly cover the ground up to almost the xtreme limit of its occurrence, when within the space of a foot

or two it fails entirely. The figure does not exaggerate the nearly straight course followed by the upper margin of the deposit (to avoid misapprehension I may say that throughout the article, in speaking of limestone, only that derived from the Lower Magnesian horizon forming the caps of the higher bluffs is regarded, the limestone found at lower levels and belonging to the Potsdam series being carefully excluded).

I would call attention to the fact that all the examples given lie over against projecting angles of the primary bluffs. To reach the position occupied, material must have moved in defiance of the law which requires that it shall travel along the shortest available course from a higher to a lower level. We are obliged to account not for a few sporadic cases of such transportation merely, but for such an abundance as really amounts to a concentration. I therefore feel justified in saying that under existing conditions it is quite impossible that the material should have reached its present lodgment by rolling from the higher bluffs. In the case of the deposits on the buttresses, I have speculated as to the possibility of their having been earlier accumulations antedating the formation of the circs. But the hypothesis fails to explain all the facts even in these cases, and is of no assistance whatever in cases like those illustrated in Fig. 5 or Fig. 7.

The only tenable hypothesis remaining, as it seems to me, is that the valleys were filled with wind-drifted snow, which was piled up around the higher bluffs, so that only their limestone tops rose above. In such a case the limestone débris which reached the upper edge of the drifts would sooner or later work downward to a lodgment wherever the slope and other conditions were favorable. This involves the further assumption that the snow had been compacted to practically the consistency of glacier ice. So far as I have been able to bring it to a test, this hypothesis explains the various peculiarities remarkably well. All the localities showing limestone débris thus far discovered, are in places where, under the hypothesis, they would have been most likely to occur. Compare Fig. 5 and explanatory

notes. The minor features of distribution also harmonize well with it; for example, in Fig. 6, limestone is wanting on the north side of the buttress. But this side is remarkably high and the height is maintained for a long distance, and the upper surface of a drift having the average slope would have fallen much below the top of the perpendicular escarpment. Conversely there are other buttresses so small that a drift having the average slope would have buried them completely, and these also are destitute of the limestone.

It is evident that on this hypothesis the limestone accumulations furnish data from which we may calculate approximately some of the dimensions of the drifts. In some of the circs the slope may have been as high as 20° in places, but the average appears to have been nearer 15°. In the valleys it was much less, apparently ranging from 10° or 12° down to 4° or 5°. The greatest vertical thickness appears to have ranged between 200 and 250 feet in the valleys and between 80 and 120 feet in the circs

The hypothesis does not necessarily imply that the big drifts developed glacial motion, since the transit across their upper surfaces might have taken place though the drifts were themselves stationary. But if we may accept the existence of large bodies of snow in the valleys, as probable, the indices of glaciation shown in the lower portions of the same valleys gain greatly in importance.

The facts above given regarding the distribution of limestone on the bounding buttresses of circs, seems to render it desirable that some notice should be taken of their low level deposits. Unlike those connected with the larger valleys, these are almost wholly external, and have the form of alluvial cones. As seen in section, they display the concentric structure lines indicating the successive stages of their upbuilding. These are more pronounced on either side of the center where also the material is usually fine.

Along the center, or axis, bedding planes are often faint, or lacking, and much heavy material is included. As might be

expected, the coarse material is a fairly representative assemblage from the different horizons.

So far there is nothing to suggest glacial action. But two bowlders seen in the railroad cutting are noteworthy on account of their character, and certainly suggest some such agent. They are tabular forms six or seven feet across, and two to three feet thick, derived from the thin-bedded, impure limestones of the Potsdam series and are extremely fragile. One, indeed, is divided near the middle by what has every appearance of being an old joint about half an inch wide, and the sides still parallel. Their nearest point of origin was several hundred feet distant. How such masses could have traveled even a short distance without falling to pieces, it is hard to see, unless they were firmly embedded in some matrix.

From a variety of circumstancs, I have the impression that the circs have been well cleaned of rocky débris, and that such material is now accumulating at their upper ends. The indications are strong that little save the finer débris now passes out. For the present, however, I should not care to lay much stress on these impressions.

While these deposits must be regarded as essentially non-glacial, there does not appear to be anything inconsistent with the assumption that occasionally during periods of exceptional activity, glaciers may have advanced on to them for short periods.

The field is very far from having been exhaustively worked, and until evidence is more nearly complete I prefer to reserve final expression of opinion.

G. H. Squier.

FUCOIDS OR COPROLITES.

THE middle part of the Devonian section seen along the ississippi River between Hampton in Illinois and Muscatine Iowa consists of a shaly limestone, which is quite rich in fos- s.[1] From this horizon I have for some time collected certain ructures, which have a close resemblance to the fossils described James Hall under the name *Spirophyton*,[2] and which occur in e rocks of the Hamilton period in New York. The fossils found ere consist of flat cakes of calcareous material, from one to six illimeters in thickness and from five to thirty centimeters in idth, intercalated among the layers of the rock, mostly lying rallel with these, and presenting an endless variety of forms Figs. 1–8). The flat surfaces are bent in a succession of wave- ke, crescentic, low and wide ridges, which become confluent d indistinct near the margin. Generally the widest ridges ve a corresponding depression on the opposite side of the ke.

Much of Hall's description of *Spirophyton* is perfectly appli- ble to these fossils. Their substance is often "scarcely separ- le from the stony matrix," especially when the containing ck is unweathered. The wave-like ridges are "frequently not stinctly limited on the outer margin," which then appears to continuous with a lamina in the rock (Fig. 8). In one instance ere is a shallow groove following the edge of the cake on ther side (Fig. 1) and resembling that seen in Hall's figure of *pirophyton typum*.[3] The substance of the cake contains frag- ents of "small shells or fragments of shells." One of these is

[1] The part of the section to which is here referred is No. 4 in my paper, A Brief scription of the Section of Devonian Rocks, etc., published in the Journal of the n. Soc. of Nat. Hist., Vol. XIX, No. 3, pp. 93–95.

[2] Observations upon some Spiral-Growing Fucoidal Remains, etc., 16th Report on State Cabinet of Nat. Hist., JAMES HALL, 1861–2, 76–83.

[3] HALL, loc. cit., Pl. II, Fig. 2.

apparently a minute pteropod. I have, however, been unable to find any spiral or helical forms like that of *Spirophyton typum*. The nearest approach to it is a twisting of that end of the cake toward which the concave sides of the ridges are directed (Fig 7).

There are several circumstances which point to a mechanical origin of these structures. The material of which they consist is a compact calcareous mass apparently identical to that of the surrounding rock. It is difficult to explain how this could have been introduced in such quantity and in such condition into the interior of a soft pulpy seaweed, and still have permitted the plant to leave a mold of both of its surfaces in the accumulating sediments. Another circumstance of similar significance is the indistinctness of the margins of some of the specimens. In their shapes, moreover, there is an indefinable lack of that uniformity of design which we are accustomed to find in organic forms. Unless certain ones are selected and others left out, classification on this basis seems impracticable. From Hall's description of the spiral-growing fucoids in the Devonian rocks in New York, it is evident that these also are variable in form, for he states that "the larger fronds not unfrequently present irregularities and distortions, both from unequal growth and from accident, evidently having been very flexible and easily disturbed," and he refers to some of the specimens as being "detached portions which have been distorted by pressure after their separation."

EXPLANATION OF PLATE VII.

FIG. 1. Dimensions: length, 19^{cm}; breadth 5.3^{cm}; average thickness, 2.5^{mm}.

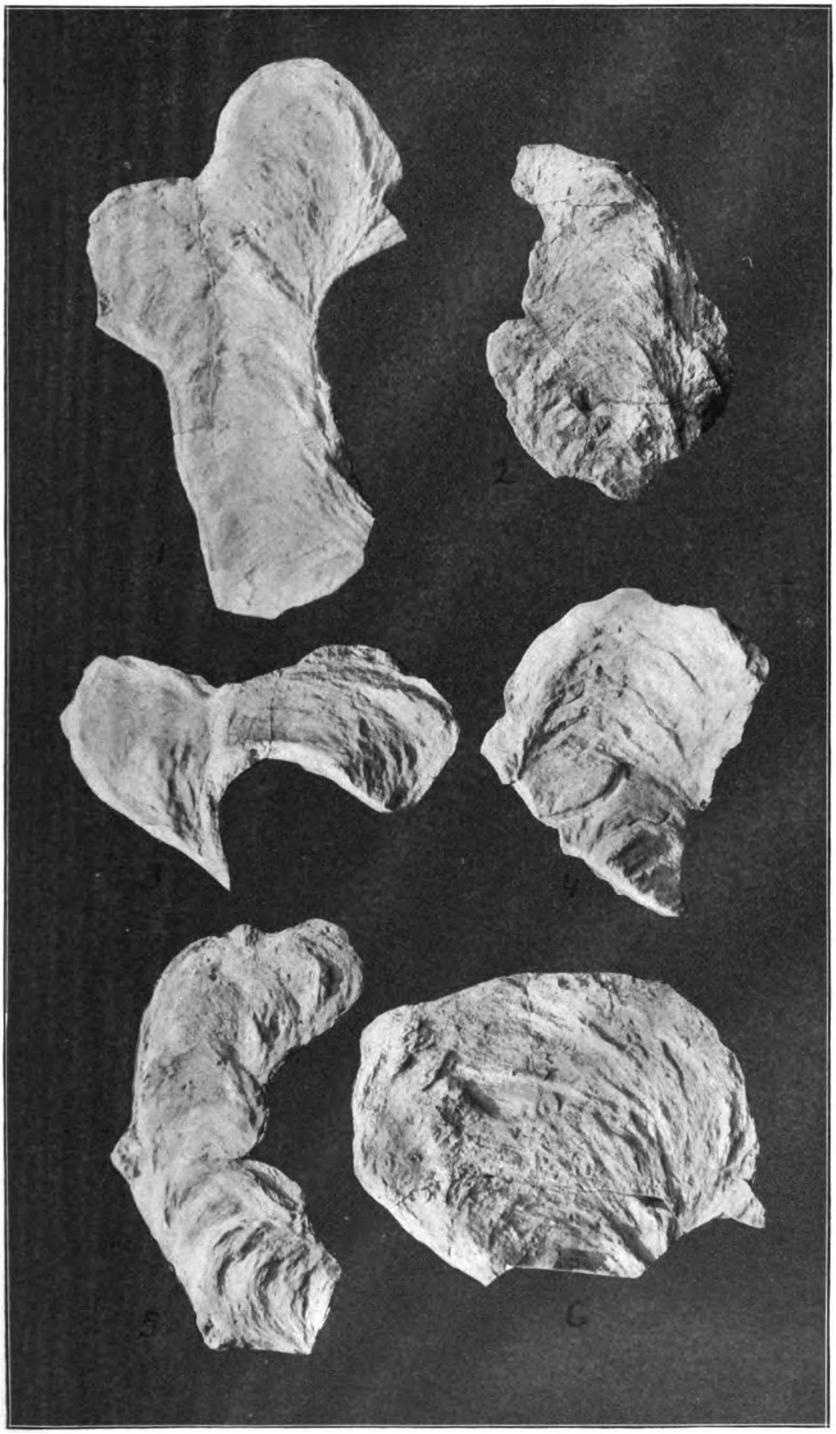
FIG. 2. Dimensions: length, 12.5^{cm}; breadth 8^{cm} at the widest point; average thickness, 2^{mm}.

FIG. 3. Dimensions: greatest diameter, 13^{cm}; average thickness, 4^{mm}. Evidently fragmentary.

FIG. 4. Dimensions: length, 12^{cm}; greatest breadth, 10.5^{cm}; thickness from 6^{mm} to 2^{mm}.

FIG. 5. Dimensions: length, 16^{cm}; average breadth, 5^{cm}; average thickness, 4.5^{mm}.

FIG. 6. Dimensions: greatest diameter, 14^{cm}; average thickness, 4.5^{mm}. Fragmentary.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The general appearance of the western specimens is such as to suggest that they have been formed from flowing mud. In some instances the crescentic ridges overlap, as if the flow had run over on itself. Near the edges of the specimens planes of divisions are sometimes seen, which readily might be accounted for as planes of differential motion in moving mud, but which seem difficult to explain if the specimens be regarded as imprints or casts of sea-weeds.

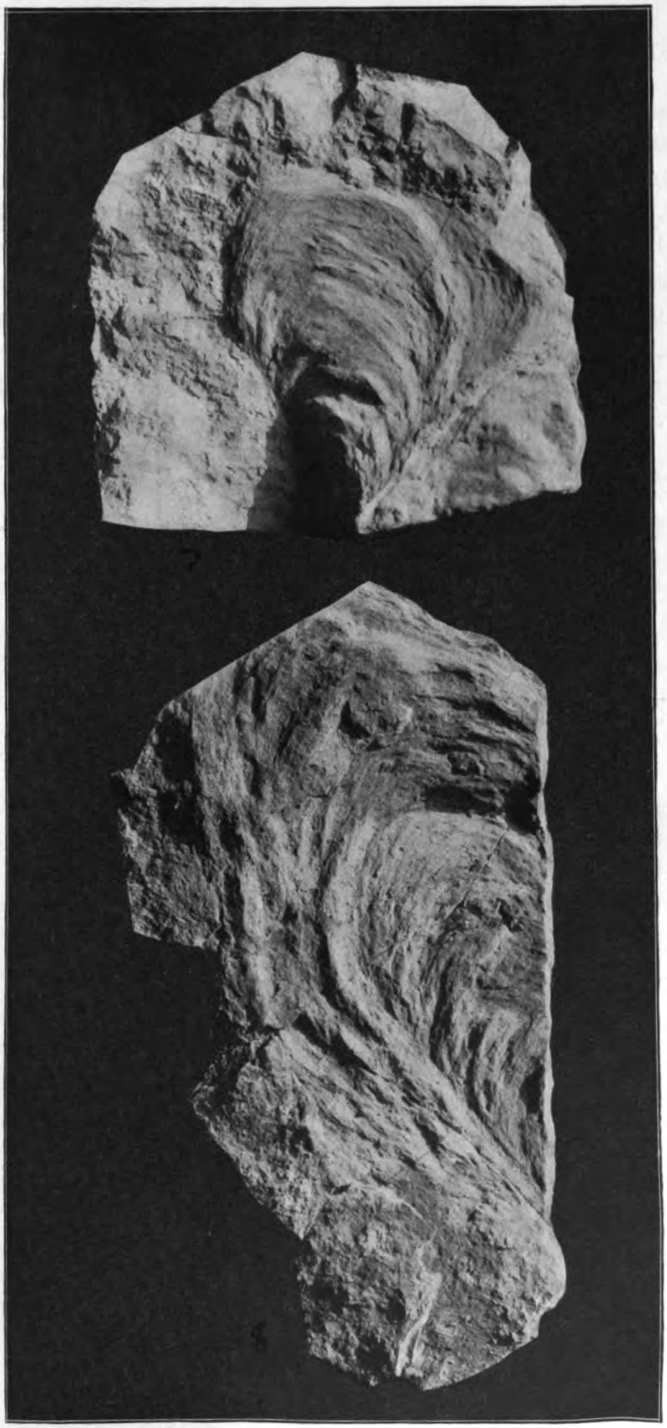
But the resemblance between these western specimens and *Spirophyton* is in general so perfect that there can hardly be any doubt that both have the same origin, and it is evident that the regular spiral frond of the latter, however rarely found, cannot have been produced except by the intervention of some organic agency. The quiet sea-bottom indicated by the nature of the sediments containing the fossils also preclude the possibility of the occurrence of mud-flow in the ordinary way under the conditions of deposition of the containing rock.

It seems, however, that cakes like these might be formed in just such situations from the voided contents of mud-eating animals, such as sea-cucumbers. These are known to burrow in the mud, far out in the sea, and to extract their food from such fragments of organic substance as they find in the ooze, mud, and sand with which they fill themselves, and which is afterward expelled by contractions of the visceral muscles. This may, no doubt, take place down in the mud as well as on the surface of the sea-bottom. If we suppose that the cakes have been formed in such a way, it is easy to account for their diversity of form—even when this takes on the complex twist of a spiral—and there will be no difficulty in explaining how it came about that they are molded from the same material as the surrounding matrix. A loose mud slowly forced out from a receding tube

EXPLANATION OF PLATE VIII.

FIG. 7. A specimen in the matrix. Length, 12^{cm}; breadth, 10^{cm}; thickness, 2^{mm}.

FIG. 8. Fragment of a large specimen cut by a joint in the rock obliquely, and confluent at the edge with a layer in the rock. Greatest length, 21.5^{cm}; breadth, 14^{cm}; average thickness, 4.5^{mm}.



can be made to settle in heaps which will have a noticeable resemblance to these peculiar fossils. This new interpretation of an obscure class of objects is given merely as an aid in their study. Though the holothurians are referred to as the animals most likely to produce coprolites of this kind, it is believed that any other mud-eating species of burrowing habits may just as well have done the work—soft animals, perhaps, that were sufficiently protected by their concealment in the ocean mud to render unnecessary any hard parts, which might have left less uncertain traces of their existence.

J. A. UDDEN.

ROCK ISLAND, ILL.

ZIRKELITE — A QUESTION OF PRIORITY.

IN the *Mineralogical Magazine*, Vol. XI, pp. 86–88 (read June , 1895) is described a new mineral containing zirconium, anium, lime, iron, etc., under the name of Zirkelite. This per was prepared by my friend, Dr. E. Hussak, and by Mr. T. Prior. Later Mr. Prior (*loc. cit.* pp. 180–183, read Nov. , 1896) published an analysis of the same mineral.

I wish to protest against the use of the name Zirkelite for is mineral on the ground of the prior use of it to designate a mmonly occurring rock belonging to the basaltic family.

When two subjects are so intimately connected as mineralogy d petrography it does not seem to be for the interest of science at names should be duplicated in them. So true is this that I andoned the name Rosenbuschite, which I had given to a class rocks in honor of Professor Rosenbusch, because only a few eeks previously it had been employed to designate a new ineral.

The term Zirkelite was used by me in 1887, or seven years fore it was taken by Messrs. Hussak and Prior. (See Preninary Description of the Peridotites, Gabbros, Diabases, and ndesites of Minnesota, *Bulletin No. 2*, Geological Survey of innesota, 1887, pp. 30–32.) It was used to designate the mmonly occurring altered conditions of basaltic glassy lavas hich are often called diabase glass, etc. Zirkelite occurs formg the entire mass of thin dikes, and the exterior parts of any dikes of diabase and melaphyre, as well as the surface of d lava flows like the melaphyres and diabases of Lake Supeor, Newfoundland, and elsewhere. Zirkelite holds the same lation to tachylite that diabase and melaphyre do to basalt, *e.*, an older and altered type. The macroscopic and microopic characters of this rock were given in the locality cited ove.

The term Zirkelite was again used in the same way in my *Report of the Geological Survey of Michigan* for 1891–2 (1893, pp. 90, 97, 138, etc.).

It was also published in my classification of rocks given in the *Catalogue of the Michigan College of Mines* (Michigan Mining School), 1891–2, p. 104; 1892–1894, Table XI; 1894–1896, Table XI.

Further the term Zirkelite is defined in accordance with my usage in Lewinson-Lessing's *Petrographisches Lexikon*, 1893, p. 252); and accounts of it are given in the *Neues Jahrbuch für Mineralogie*, 1893, II, p. 292, and in Kemp's *Handbook of Rocks*, 1896, p. 170.

M. E. WADSWORTH.

MICHIGAN COLLEGE OF MINES, HOUGHTON, MICH.,
December 17, 1897.

[The prior use of the name *Zirkelite* is certainly established, but it is a question how far a petrographer is justified in stigmatizing the name of a fellow worker by attaching it to an indefinitely decomposed and ill-defined rock.—J. P. I.]

EDITORIAL.

ditors Journal of Geology:

I WOULD like to call attention to the constant misuse of a reign word much used by glacial geologists. The word *aas* in e Danish, *ås* in Swedish, which in Norway is used for a rounded ll, and in Sweden and Finland especially for those long gravel dges which are clearly of glacial origin, has its plural *åsar.* he word is pronounced like the *oas* of *boast,* and really the best ay to transliterate it into English would be to spell it *oas* rather an *os*, as the long sound would then be more certainly given it. he plural would then be *osar* or *oasar*, which is, perhaps, preferle to *oases* for obvious reasons.

Therefore the writers who speak about "*an osar,*" and menon "*the osars,*" are producing the same kind of horrible hybrids at foreigners would who should speak of "*an oxen*" or "*I saw ree mices,*" mistakes of a kind which, in writing, are unnecesry.

L. V. PIRSSON.

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ANY protest that will help to a better use of terms in science elsewhere is to be welcomed as a contribution toward the lief of one of the most grievous burdens of the intellectual orld. The incompetencies and inadaptabilities of our vehicle thought, to say nothing of its absurdities, are already most rious obstacles to intellectual progress, and they are daily owing in intensity and threaten to become altogether unenrable in the near future. In former times, when the substance thought was limited, the intellectual gymnastics involved in astering the idiosyncrasies of language were not without their mpensations. But the time has come when even the essence

of the most imperative thought has grown to such magnitude that any labor wasted upon the trammelings of verbiage falls into the category of the reprehensible. It would be an interesting investigation which should show how great an amount of ignorance of vital truths is justly chargeable to the time consumed in gaining a questionable mastery of the needless, not to say the positively pernicious, factors of a language whose evolution is a century behind the times. It would be an instructive investigation in criminology which should ascertain how much of suffering, death, and other disasters arise from crowding aside instruction in vital matters to make room for the dull grind upon the senseless conventionalities of a delinquent language.

To the already deplorable state of things chargeable to linguists, teachers, and the common public, the devotees of science are adding their special inflictions, and if present practices continue there will apparently be no remedy in the future but open rebellion. It is said that the number of organic species and varieties has grown already into the neighborhood of one million, and each of these is burdened with a binomial, if not a trinomial, designation consisting usually of an artificial breccia of Greek, Latin, local, personal, and other verbal fragments, rudely stuck together and finished off at the end in Latin fashion. They are "neither fish nor flesh, nor good red herring."

Our mineralogical terminology which endeavors to impose on all futurity unmouthable distortions of the names of insignificant streams or mountains or villages or collectors or scientific friends unworthily rivals the biological monstrosities. And when we come to compound these into the names of rocks, in pursuance of a most natural and laudable system of nomenclature, their uncouthness is more than doubly emphasized, and becomes almost prohibitory. If geologists in their own field are not coequal sinners, it is, perhaps, only due to a less urgent need for terms. When we contemplate that to which this inconsiderate practice will inevitably lead as the number of varieties and species and distinctions increase with the progress of research, the seriousness of the evil becomes intensified. When

e compute the loss to the acquisition of the essential elements science which must ensue if this system is perpetuated through e five to ten million years which the solar prophets assign as e possible future of the habitable earth the magnitude of the fliction grows to prodigious dimensions. It may be confidently edicted, however, that there will be a revolt in the not distant ture if a rational movement toward reform is not soon inaugu-ted. In the meantime every little reform has an importance, ot only in its own merit, but also in its moral effects as a step wards general reform.

Back of the special criticism of Professor Pirsson there is a eneral question which invites attention in connection with his otest: What considerations shall guide us in the endeavor to cure better practice? The word *ås*, *åsar*, was anglicized to sar, osars, a half century ago, and may be found current in the ritings of Murchison, Desor, the elder Hitchcock, and others. ractice has been divided ever since between the alternative evils introducing into the English language a word of irregular ariation and uncertain pronunciation (to English people) with s consequent infelicities, or of ruthlessly modifying the Swedish ord to suit English practice, with the barbarisms which Profes-or Pirsson points out.* There is, however, a *tertium quid*, to which mericans are quite generally turning. It is the avoidance of oth these alternatives and the adoption of the term *esker* instead, hich in form and phonic nature is more acceptable. Whatever ay be the method of formation of the plural of the ultimately erfected world language, it is quite certain that it will not follow e Swedish analogy *ås*, *åsar*, because this is not inherently meri-orious. Hence we do the English language a poor service and ut obstacles in the way of the ultimate common language by troducing a form not in itself worthy to endure. It may be rged as an objection to the term esker that *ås* had currency at n earlier date. If we are to give the law of priority its widest pplication, and bow unhesitatingly before it, the objection holds ood. The writer has himself previously yielded to it. But on ller consideration he withdraws from this position and favors

the use of the inherently preferable term esker. While due regard should doubtless be paid to the law of priority, it seems obvious upon mature consideration that all future generations should not be made to suffer unduly for the infelicities of the first usage often carelessly inaugurated. The improvement of the language should have first thought, and be given determinative weight in all permissible cases. The evolution of a common vehicle of thought for all the world will grow more imperative as intercommunication and common sympathy become more universal, and the rapid increase of vital knowledge and the more strenuous demands of a higher civilization will require that this vehicle shall be not only surpassingly rich in its resources, but economical in its modes of operation. Intellectual wastefulness is as reprehensible as material wastefulness, and our vehicle of thought should be as assiduously improved in the interest of economy and effectiveness as our vehicles of property or person.

T. C. C.

Reviews.

Fourteenth Annual Report of the New York State Geologist for 1894. James Hall, State Geologist.

This volume of 669 pages, besides containing the short report of the state geologist giving an account of the work done under his direction, embraces several valuable papers upon the geology and palæontology of New York state. The brief reviews of these papers here given are taken largely from those written by the state geologist and printed in his report at the beginning of the volume.

1. *A Preliminary Description of the Faulted Region of Herkimer, Fulton, Montgomery, and Saratoga Counties.* By N. H. Darton, pp. 31–56, Pls. I–IX, Figs. 1–12.

The field work upon which this paper is based was done in connection with the preparation of the geological map of the state. It describes in detail a region of country which was originally described by Vanuxem in his report on the geology of the Third District. It gives an account of the general relations of the faults, and describes in detail those at Little Falls, on the East Canada Creek, St. Johnsville, the Noses, Fonda, Tribes Hill, Broadalbin, Hoffman's Ferry, Saratoga, and Lake George.

The region is a general monocline with sediments of slightly varying dip, and the faults traversing this monocline, accompanied by certain features of local disturbance, have considerably modified its regularity. As a rule, these displacements do not make conspicuous features in the topography, but one of them, at Little Falls, gives rise to one of the most striking features in the scenery of the Mohawk valley.

2. *Report on the Structural and Economic Geology of Seneca County.* By D. F. Lincoln, M.D., pp. 57–125, Pls. I–XIX, Figs. 1–30.

The subject treated in this paper is covered under three general divisions: (1) surface geology; (2) stratigraphic geology; (3) eco-

nomic geology. Under the first head are given detailed accounts of the topography, and also of the superficial accumulations, their nature, and distribution. The sections on stratigraphic geology considers each formation in succession, from the Salina to the Portage, giving the local development and variations of each with fullness and precision. Faunal characters are touched upon to some extent, no wide difference in these respects from adjoining regions being noted. Under the head of economic geology are considered all the rock products of the county, their mode of exploitation, treatment, and economic value.

3. *The Principles of Palæontology.* By FELIX BERNARD. Translated by C. E. BROOKS, pp. 130–215.

This paper is extracted from Bernard's *Eléments de Paleontologie*, Paris, 1895, and is translated and here published for the benefit of American students to whom Bernard's entire works may not be accessible. No other writer has succeeded in setting forth so clearly the actual condition of the science, its relations to other departments of knowledge, and the inherent importance of the problems with which it is wholly concerned.

4. *Development and Mode of Growth of Diplograptus, McCoy.* By R. RUEDEMANN, pp. 217–258, Pls. I–V.

The observations recorded in this paper are based upon material in a remarkably perfect condition of preservation, obtained from the Utica slate at Dolgeville, N. Y. The paper shows that these graptolites, generally occurring as isolated stipes, were actually colonies composed of a large number of such individual stipes, growing radially from a center. The structure of the central part of the colony is shown to consist in (1) a central floating sack or pneumatocyst, demonstrating that the colony was unattached; (2) a verticil of spherical gonangia, within which are found masses of young graptolites or siculæ attached to a central axis; beneath the gonangia are (3) the radiately arranged graptolite stipes attached by long, bare extensions of the axial rod or virgula of each stipe. The paper is illustrated with five plates of highly instructive drawings.

5. *A Revision of the Sponges and Cœlenterates of the Lower Helderberg Group of New York.* By G. H. GIRTY, pp. 259–322, Pls. I–VII.

In this paper the known species of the groups mentioned are redescribed, with one new genus and ten new species. Four genera of

sponges, with five species, are recorded, with thirteen genera and twenty-one species of cœlenterata.

6. *New Species of Brachiopoda described in the Palæontology of New York*, Vol. VIII, Parts I and II, 1872–1892. By JAMES HALL, pp. 323–402, Pls. I–XIV.

In this paper are published the descriptions of 106 species of brachiopoda, which were described incidentally and sometimes figured without descriptions in the recent work upon the class by Hall and Clarke.

7. *A Handbook of the Genera of North American Palæozoic Bryozoa.* With an Introduction upon the Structure of Living Species. By G. B. SIMPSON, pp. 403–699. Pls. A–E, I–XXV, and 222 figures in the text.

The first portion of this work is devoted to the recent bryozoa, and contains the history of observations upon these organisms from 1599 to the present time, followed by a bibliography and an illustrated detailed account of the anatomy.

The second part is devoted to the fossil forms from the Palæozoic rocks, and contains a scheme of classification, the bibliography of the Palæozoic species of America, a list of the genera and species described, with references to authorship and the geologic formations in which they occur. The genera described number 156, the species enumerated are about 1100. The main portion of the second part is devoted to diagnoses of the genera, illustrated by 222 figures in the text and by 25 plates.

STUART WELLER.

Petrology for Students, An Introduction to the Study of Rocks under the Microscope. By ALFRED HARKER, M.A., F.G.S. Second Edition, Revised. Cambridge, England, 1897.

A review of the first edition of this book by the present writer appeared in this JOURNAL, Vol. III, 1895, p. 856. The present edition reproduces the original text, with slight alterations, some of which follow the changes that appeared in the third edition of the second volume of Rosenbusch's *Mikroskopische Physiographie*, etc., published in 1896; besides the addition of numerous notices of American and Norwegian occurrences of various rocks, with references to their descriptions. The fuller mention of American occurrences increases

greatly the value of the book for students in America, who will find it very useful for this reason.

The alteration in the title of the second group of igneous rocks, according to the classification followed in this book, namely, from that of Intrusive to that of Hypabyssal, has not obviated the necessity for the apology made in the introduction to this group of rocks in the first edition, which is repeated in the second. The newer term is as inappropriate as the former one, and the criticism made in the review of the first edition holds with equal force in the present case.

J. P. I.

Rocks, Rock Weathering and Soils. By G. P. Merrill. 8vo. 411 pp., Macmillan & Company, New York, 1897.

This admirable work brings together three subjects closely consecutive in the processes of nature but not previously associated as the subject of equally elaborate treatment in their mutual relations. The main emphasis of the work is placed on rock weathering, the description of rocks being in the main preliminary to this and that of soils a natural sequence. No attempt is made to treat rocks as such in an exhaustive way, nor soils as such. The discussion of weathering on the other hand is made as exhaustive as the present state of science will permit. The 168 pages of Parts 1 and 2 relating to minerals and rocks embrace a reasonably satisfactory treatment of these themes. This is as much perhaps as can be said of any attempt in this line in the present unfortunate condition of the classification and nomenclature of rocks and minerals. The relative fullness of treatment of the several rocks is measured in a degree by their importance in the production of soils. Very properly prominence is given to chemical composition, since this is a prime consideration in following the transition of the rocks into soils and secondary rocks. The numerous tables of analyses are a valuable feature. The use of terms is conservative and many of the intermediate stages in the gradation of one rock into another are left without specific nomenclature. The author files a protest against the tendency "which has resulted already in such monstrosities of nomenclature as *ouachitite*, *monchiquite*, *yogosite* and *absarokite*."

The subject of weathering and transportation occupies the heart of the book and constitutes its distinguishing feature. After a statement of the principles of weathering and of the agencies involved, the special

modes of alteration of the leading rocks are discussed in detail. Perhaps the most valuable contribution of the book is the series of analyses of identical rock at varying stages of decomposition, by means of which the nature of the process, in so far as it is chemical, is specifically and precisely indicated. These tables show in just what degree the process acts differentially upon the several constituents of the rock. Although the analyses are not sufficiently numerous to warrant very broad generalizations, they are very helpful in giving approximate knowledge of the relative parts played by the several constituents of rock in the disintegrating process. The results of the analyses are conveniently indicated in separate columns which severally show the percentage of loss for the entire rock, the percentage of each constituent saved, and the percentage of each constituent lost. These special studies are followed by a résumé embracing general deductions drawn from them.

The chapter on the physical manifestations of weathering treats of the more familiar effects of the process on texture, color, surface configuration and similar features. This is followed by an interesting chapter on time considerations, in which are treated the rates of weathering and the influence of position, texture, composition, humidity, temperature and other climatic conditions upon the progress of the process.

The mantle of loose material which results from the weathering, together with loose material accumulated on the surface by other agencies, the author designates *regolith* (mantle rock), and devotes the last 100 pages to its description. It is not altogether clear whether the simple fact of mantling the surface with loose material is sufficient to unify accumulations arising from quite diverse agencies and varying greatly in nature, and hence to call for a specific name of the petrographic form. The residuary clays and earths constitute a unitary formation derived directly by the processes of weathering. The glacial, eolian, and similar deposits can only be brought into the same category by largely neglecting their mode of origin and confining attention merely to their superficial disposal and their incoherent character. It may well be questioned whether the genetic factor in these cases will not usually be the one to be kept at the front, and be more often placed in contrast to the residuary earths than merged with them. Doubtless, however, the mantling feature which they possess in common will make the term regolith often convenient. The word at any rate may be left to stand or fall as experience shall dictate.

The discussion of the soils is relatively less satisfactory than most other portions of the book, but this is a subject so large in itself that a satisfactory treatment could not be expected as a theme subordinate to so broad a subject as the central topic of the book.

The essence of several of the sections on weathering were published in this JOURNAL while the author was engaged upon the studies which have taken form in this book and its readers are familiar with the excellent method of their treatment and their substantial character.

C.

AUTHORS' ABSTRACTS.

PAPERS READ AT THE MONTREAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA.[1]

Topography and Glacial Deposits of the Mohawk Valley. By ALBERT PERRY BRIGHAM.

The lower Mohawk, and a corresponding valley to the westward, are onsidered as subsequent in character, having been initiated by headvard cutting from the ancient Hudson and St. Lawrence valleys, along he strike of soft beds, to the col located by Chamberlin at Little 'alls. The Adirondack streams consequent on Palæozoic topography vere thus diverted and the Susquehanna streams were beheaded. West of Little Falls the rock floor descends toward Lake Ontario, but not iniformly, a buried rock basin above 100 feet in depth, lying east of Jtica. The present arrangement is due to glacial and aqueo-glacial rosion at Little Falls, and to aggrading from Rome eastward by glacial materials. The westward flow of the lower Mohawk glacier is onfirmed by striation at Amsterdam.

The drift deposits west of Little Falls are largely composed of deltas and benches whose altitudes indicate approximately a water level of 600 feet. This is believed to represent a lacustrine stage in which he waters had fallen below the Warren level and below Fairchild's Geneva beach, but had not yet subsided to the Iroquois plane. The dam is thought to have been at Little Falls, and of a composite nature —the sill of gneiss then standing at about 440 feet, with drift and ice blockade, in this long, sinuous, narrow gorge. Below Little Falls, marginal bodies of massive till, aggraded by water-laid material, show a fluvio-lacustrine level of 430 to 440 feet, the barrier being unknown. The next stage in the lower valley was also fluvio-lacustrine, at 340 feet. The gneiss then caused a great waterfall at Little Falls, and the lacustrine stage persisted to the eastward, while a rock gorge more than

[1] Continued from last issue.

100 feet deep was cut at Aqueduct, near Schenectady. Certain beds of massive, water-laid clay west of Little Falls, taken with similar deposits in the Chenango and Unadilla valleys, are thought to show long and quiet deposition, with perhaps considerable later erosion, before the last advance of the ice across central and southern New York.

Clastic Huronian Rocks of Western Ontario and the Relations Between Laurentian and Huronian. By A. P. COLEMAN.

The rocks of the Lake of the Woods and Rainy Lake regions of western Ontario have been excellently mapped by A. C. Lawson, who calls them Archæan and subdivides them into a lower part, the Laurentian, and an upper one, the Ontarian, further subdivided into the Couchiching and the Keewatin. The Laurentian, which consists chiefly of granite and gneiss, underlies the other two series, but has an eruptive contact with them, showing that it was the latest in age. The Couchiching is formed mainly of fine-grained gray gneiss and mica schist, of clastic origin, since the quartz is usually in distinctly rounded grains. These rocks merge into almost unchanged sandstones in a few places, as found by the writer.

The Keewatin is much more varied, consisting very largely of basic and acid eruptives with their pyroclastics; but containing also important sedimentary members, such as limestone, slate, quartzite and conglomerate. The last rock is not a basal conglomerate resting on the Couchiching or Laurentian, but comes high up in the series, since it contains mainly pebbles of eruptives and schists found in adjoining portions of the Keewatin. It may represent a break equivalent to that between the lower and upper Huronian in the states to the south, as described by Van Hise. These conglomerates contain no Laurentian pebbles so far as known.

The field relations of the three formations are very interesting, both as mapped by Lawson and as observed on the bare shores of lakes in the western Archæan peneplain. The Keewatin, and in the southern part of the region the underlying Couchiching, form sharp synclines, curving as wide meshes round the areas of Laurentian, which vary greatly in size, running from a diameter of less than a mile to about fifty miles. Starting from the center of a Laurentian area one commonly finds first granite, then gneiss having a strike parallel to that of the adjoining schist. Before reaching the schist many frag-

nts of it are usually seen embedded in the gneiss. Green Keewatin ists are generally turned to hornblende-schist near the contact, but Couchiching mica-schists are seldom much altered. Dikes of nite or felsite frequently run from the Laurentian gneiss into the tarian or Huronian rocks, as they are generally called by Canadian ologists. We have evidently here a section through a pre-Cambrian untain group, so near its base that some of the meshes run out as finished curves, erosion having eaten completely through them. om the steep dip of the schists in the synclines and the width of me of the Laurentian batholites we must infer that these dome-aped mountains were of considerable height, probably comparable the highest present ranges.

Lawson has computed the thickness of the two members of the uronian (Ontarian) at about five miles each ; so that in some places ,000 feet of sediments, in the upper part mixed with eruptives, ust have rested on the old sea floor ; as great a thickness as we find the sediments preparing the way for later mountain ranges.

This brought about a rise of the isogeotherms sufficient to produce drothermal fusion of the rocks underlying the sediments.

As the usual theory of mountain building, by lateral thrust, can oduce only folds, these domed mountains must have been elevated in me other way. They may be compared with Gilbert's laccolites or C. Russell's plutonic plugs, or perhaps more nearly with the struc-re of the Black Hills, but present important differences from all of ese types of mountains.

The writer suggests that the hydrothermally fused acid Laurentian agma was lighter, both because of its heat and specifically, than the erlying rocks; and so, by the laws of hydrostatics, slowly crept ward the points where the load was smallest, the heavier Huronian cks sinking toward the lower portions, where they were ultimately ipped in as sharp synclines.

The region which typically displays this system of Huronian eshes enclosing Laurentian batholites is more than two hundred iles long and a hundred and twenty broad. How much farther milar conditions prevail cannot be known until the Canadian rchæan is more completely mapped than at present.

The Laurentian has been shown to form eruptive contacts with the Iuronian eighty miles north of the Lake of the Woods, and in the udbury district, five hundred miles to the east. The Hastings series,

as well as the Grenville series in eastern Ontario and Quebec, probably the equivalents in age of the western Huronian, show similar curving bands and eruptive contacts of the underlying Laurentian, as described by Adams, Barlow, and Ells; and the same is true, in part at least, of Labrador, as described by Lowe.

On the other hand, the Huronian regions in the United States south of Lake Superior, and also in New Brunswick, present a basal conglomerate resting unconformably on the Laurentian, according to Van Hise and Dawson. It may be that in the latter cases the thickness of sediments was not great enough to depress the Laurentian floor to the level of fusion or plasticity; or that the Huronian, as recognized in these regions, is really younger and overlies the upturned edges of the rocks described as Huronian in the northern Archæan. Some remarks in Van Hise's pre-Cambrian geology seem to suggest this.

It is likely that eruptive contacts of batholitic masses with overlying rocks exist under every great mountain chain; though the "Fundamental Complex" thus arising is disclosed only in the more ancient and therefore more deeply eroded mountain systems. Something like this has been shown to exist in British Columbia by Dawson, but of Jurassic age. Under the later mountain systems, however, the arching of anticlinal folds probably aided the uprising of the plastic base; and we may suppose that the core of granite and gneiss forms long belts rather than approximately round batholites.

The term Laurentian has been used in the paper to include granites and gneisses of later age than the Ontarian or Huronian rocks, following the custom of the Canadian geologists who have worked in western Ontario. As this use differs from Logan's original definition, it might be better to substitute another name, unless it shall appear that the relation described above is universal in North America, and that the supposed Huronian found to rest uncomformably on the Laurentian is really of later age than the true Huronian.

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CHEMICAL AND MINERAL RELATIONSHIPS IN IGNEOUS ROCKS.

THE attempt to correlate the mineral composition of igneous ...cks with the chemical composition of their magmas, that is, of ...ch rock as a whole, is rendered difficult by the chemical char...ter of the rock-making minerals themselves, and by the fact ...t no fixed association of minerals necessarily results from the ...ystallization of an igneous rock magma, the association in a ...ven case being affected to a greater or less extent by the ...ysical conditions attending the solidification of the magma.

The pyrogenetic rock-making minerals are mostly silicates of ...veral elements which may enter in different proportions into ...e composition of distinct minerals; so that the chemical dif...ence between a number of these minerals lies in the propor...ns of their chemical components rather than in the kinds. ...nong the more important rock-making minerals, including the ...ief silicates, together with quartz and magnetite, there is no ...ement found only in one mineral. Each constituent may enter ...veral of them. Nevertheless there are limitations to the kinds ... elements constituting certain minerals, as well as more or ...s definite proportions to their amounts in each case. But it is ... be remembered that with the exception of quartz none of them ...s an absolutely fixed composition, but each belongs to an ...morphous or morphotropic series, that is, represents a more ... less variable mixed salt or crystal. Variations in the chemical ...nstituents of rock magmas will affect the chemical composi-

tion of several minerals in any case, as well as the relative proportions of all the minerals constituting the rock.

The relations between the minerals crystallized from a rock magma and the physical conditions attending its solidification have been scarcely more than recognized in a general way, though many examples have become well known. But enough has already been learned to warrant the conclusion that the attendant physical conditions exert a definite control over the grouping of the chemical elements in the molten magma, whereby the kind and character of the minerals crystallizing from it are affected. And it may be confidently predicted that careful comparison of the chemical composition of rocks with their exact mineral composition and texture, and with their mode of occurrence as geological bodies, will eventually lead to the discovery of these relationships.

Realizing the difficulties in the way of a complete correlation of the mineral and chemical composition of igneous rocks, and the limitations of our present knowledge both as to the relationships just mentioned, and as to the actual chemical composition of many rock-making minerals, it may still be possible to make a beginning of the correlation by attempting to state certain relationships between the theoretical molecules of the chief rock-making minerals and the chemical composition of igneous rock magmas.

Composition of the rock-making minerals.—Owing to the com plexity of even this preliminary correlation, it is advisable to consider only the more important rock-making minerals, leaving the less frequent ones for future elaboration of the discussion. The former may be grouped as follows: Quartz, the feldspathic minerals: the feldspars proper, with leucite, nephelite and the sodalites; muscovite, forming a link between feldspathoid minerals and ferromagnesian minerals; biotite and the other ferromagnesian minerals: olivines, pyroxenes, amphiboles; besides magnetite. Minerals necessary to a fuller discussion are melilite, garnet, titanite, perofskite, apatite, zircon, and others.

The chemical composition of each of these minerals, or groups

f minerals, may be expressed in the simplest form, as in the fol-
›wing list, first by the empyrical formulas, second by the
ualistic, the convenience of the latter being apparent when com-
arison is made with the chemical composition of the rocks, as
xpressed in the usual statement of analyses.

uartz,	SiO_2	SiO_2
rthoclase,	$KAlSi_3O_8$	$K_2O.Al_2O_3.6SiO_2$
oda-orthoclase, oda-microline,	$(K,Na)AlSi_3O_8$	$(K,Na)_2O.Al_2O_3.6SiO_2$
lbite,	$NaAlSi_3O_8$	$Na_2O.Al_2O_3.6SiO_2$
ligoclase, ndesine, abradorite,	m $(NaAlSi_3O_8)$ n $(CaAl_2Si_2O_8)$	
northite,	$CaAl_2Si_2O_8$	$CaO.Al_2O_3 2SiO_2$
eucite,	$KAlSi_2O_6$	$K_2O.Al_2O_3.4SiO_2$
ephelite,	$KAlSi_2O_6$ n $(NaAlSiO_4)$	
oda-nephelite,	$NaAlSiO_4$	$Na_2O.Al_2O_3.2SiO_2$
odalite,	$Na_4(AlCl)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_2]+2NaCl$
auynite,	$Na_2Ca(NaSO_4.Al)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_2]+2CaSO_4$
osite,	$Na_4(NaSO_4.Al)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_2]+2NaSO_4$
uscovite	$KH_2Al_3Si_3O_{12}$	$(K,H)_2O.Al_2O_3.2SiO_2$
iotite,	$(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ or $2[(H,K)(Al,Fe)SiO_4]$ $(Mg,Fe)_2SiO_4$	 $2[(H,K)_2O.(Al,Fe)_2O_3.2SiO_2]$ $2(Mg,Fe)O.SiO_2$
livine,	$(Mg,Fe)_2SiO_4$	$2(Mg,Fe)O.SiO_2$
yroxenes		
Enstatite,	$Mg_2Si_2O_6$	$MgO.SiO_2$
Hypersthene,	$(Mg,Fe)_2Si_2O_6$	$(Mg,Fe)O.SiO_2$
Diopside,	$CaMgSi_2O_6$	$CaO.MgO.2SiO_2$
Salite,	$Ca(Mg,Fe)Si_2O_6$	$CaO.(Mg,Fe)O.2SiO_2$
Augite,	$Ca(Mg,Fe)Si_2O_6$ $(Mg,Fe)(Al,Fe)_2SiO_6$	$CaO(Mg,Fe)O.2SiO_2$ $(Mg,Fe)O.(Al,Fe)_2O_3.SiO_2$
Acmite,	$NaFeSi_2O_6$	$Na_2O.Fe_2O_3.4SiO_2$
mphiboles		
Hornblende,	$Ca(Mg,Fe)_3Si_4O_{12}$ $(Mg,Fe)_2(Al,Fe)_4Si_2O_{12}$ $Na_2,Al_2Si_4O_{12}$	$CaO.3(Mg,Fe)O.4SiO_2$ $(Mg,Fe)O.(Al,Fe)_2O_3.SiO_2$ $Na_2O.Al_2O_3.4SiO_2$
Arfvedsonite,	$(Na_2,Ca,Fe)_4Si_4O_{12}$ $(Ca,Mg)_2(Al,Fe)_4Si_2O_{12}$	$(Na_2,Ca,Fe)O.SiO_2$ $(Ca,Mg)O.(Al,Fe)_2O_3.SiO_2$
Riebeckite,	$Na_2Fe_2Si_4O_{12}$ $FeSiO_3$	$Na_2O.Fe_2O_3.4SiO_2$ $FeO.SiO_2$
agnetite,	Fe_3O_4	

From this it will appear into how many different molecules
ıy chemical element many enter. In order to simplify the

problem further, the several kinds of molecules may be presented in the following manner:

Elements	Kinds of molecules		Kinds of minerals
K, Na, Al,	$(K,Na)_2O:AlO_3:SiO_2$ ::	1:1:6	orthoclase, albite
		1:1:4	leucite (amphibole)
		1:1:2	nephelite, sodalite(with excess of Na.)
	$(K,H)_2O:Al_2O_3:SiO_2$ ::	1:1:2	muscovite ($Al_2O_3 > K_2O$) .
K, Na, Al, Fe,	$(K,H)_2O:(Al,Fe)_2O_3:SiO_2$ ::	1:1:2	mica (biotite)
Na, Fe,	$Na_2O:Fe_2O_3:SiO_2$ ::	1:1:4	acmite, riebeckite
Na, Fe, Ca,	$(Na_2,Ca,Fe)O.SiO_2$		arfvedsonite
Ca, Al,	$(CaO:Al_2O_3:SiO_2$ ::	1:1:2	anorthite
Ca, Mg, Fe,	$CaO.(Mg, Fe)O.2SiO_2$		pyroxene
	$CaO.3(Mg, Fe)O.4SiO_2$		amphibole
Mg, Fe,	$(Mg,Fe)O.SiO_2$		pyroxene
			olivine, mica
Mg, Fe, Al,	$(Mg,Fe)O.(Al,Fe)_2O_3.SiO_2$		pyroxene, amphibole

The alkalis combine with an equal number of molecules of alumina in the feldspathic minerals (except sodalites). These are polysilicates, metasilicates and orthosilicates; also in one of the amphibole molecules; while in muscovite part of the potassium is replaced by hydrogen. The alkalis with hydrogen enter into an orthosilicate, mica molecule with alumina and ferric oxide in the proportion of 1 : 1, the potash being generally less than alumina. Soda enters into a metasilicate molecule with ferric oxide, in the acmite molecule. It combines with lime and ferrous oxide in the metasilicate, arfvedsonite molecule. Calcium oxide enters an orthosilicate molecule with alumina in proportions of 1 : 1.—anorthite. Calcium occurs with magnesium and iron in metasilicate molecules in pyroxenes and amphiboles, which differ in the relative proportions of CaO:(Mg, Fe)O; in the first case in the ratio 1 : 1; in the second, 1 : 3. Magnesium and ferrous iron usually occur together in variable proportions, either in a metasilicate molecule with calcium in monoclinic pyroxenes and amphiboles, or without calcium in metasilicate molecules in orthorhombic pyroxenes, or in orthosilicate molecules in olivine and mica. They combine with aluminium and ferric iron in a subsilicate molecule in pyroxenes and

amphiboles. Magnesium may occur without iron in metasilicate molecules, in diopside with calcium, and in enstatite without calcium. The alkali-alumina silicates may be polysilicates, metasilicates or orthosilicates. The ferromagnesian silicates may be metasilicates, orthosilicates or subsilicates. Iron may occur uncombined with silica in the form of magnetite, and silica may occur uncombined with other elements in the form of quartz or tridymite.

Preliminary correlation.— Some of the more evident relationships between the pyrogenetic minerals in igneous rocks and the chemical composition of the magma have been stated in a previous article in this volume.[1] They are : the usual occurrence of quartz with the polysilicate feldspars, and its non-occurrence with the meta- and orthosilicate feldspathic minerals : leucite, nephelite and sodalite; also the relation between these and the percentage of silica in the rock — the highest of these silicates always forming which is possible with the available silica in the magma. Another law seems to be that the alkalis control an equal amount of alumina, forming alkali-feldspathic molecules, and that aluminium in excess of this may combine with calcium to form anorthite molecules, or with magnesium and iron to enter pyroxene and amphibole molecules. Soda does not seem to unite with ferric oxide to enter pyroxenes or amphiboles in any considerable amount unless it is in excess of alumina. The metasilicate, orthorhombic pyroxenes, hypersthene and enstatite, usually occur in the more siliceous rocks instead of the orthosilicate, olivine, which usually occurs in the less siliceous rocks. But this is not an invariable rule, and olivine occasionally occurs in the more siliceous rocks (dacite) and not unfrequently in the presence of quartz. The orthosilicate, mica, commonly occurs in highly siliceous rocks together with quartz; pyrogenetic muscovite exclusively so. Biotite also occurs in rocks low in silica. Its range of occurrence bears no fixed relation to the percentage of silica in the rock. Magnetite occurs in rocks of all degrees of siliceousness and is not directly dependent on the

[1] On Rock Classification, JOUR. GEOL., Vol. VI, pp. 96–98.

amount of silica in the magma. It frequently occurs in association with quartz or tridymite. It is a general law that the ferromagnesian minerals become more abundant as the quartz and feldspathic minerals become less abundant.

A method of correlating the chemical and mineral composition of igneous rocks on a basis of the silica percentage and of the relative amounts of alkali in each case has been presented in the article in this volume[1] already cited. It is now proposed, without repeating what has been stated in that connection, to discuss in greater detail some of the relations between the mineral and chemical constituents of igneous rocks by making use of similar diagrams. In order to do this it will be necessary to start with the simplest assumptions, and those that appear to rest on the more general laws. Having obtained some of the simpler conceptions, more complex ones may be attempted with less danger of confusion.

It is possible to obtain an idea of the range of quartz and of leucite, nephelite and sodalite in igneous rocks by considering the most favorable cases for their occurrence, and afterwards the conditions that would modify their production. In order to render the discussion as simple as possible it is advisable to consider the extreme cases in which the alkali is either wholly soda or wholly potash. In Diagram 1 the black spots represent the rocks in which the soda is more than twice as great as potash, and the red spots those in which the potash is greater than soda. They correspond to the spots on Diagrams 2 and 4, Plates I and II of this volume. They are introduced to aid the imagination. The significance of the lines is explained in the text. For the phrase "the analysis or analyses of rocks" in the discussion of the diagrams the phrase "the rock or the rocks," will be substituted, it being understood that only the chemical attributes of the rocks are under discussion.

I. Let us first postulate the case of magmas whose *alkali is wholly soda*, and in which the *molecules of alumina are always in equal proportions to those of soda.* Then with no other constituent

[1] Loc. cit., pp. 98–103.

except varying percentages of silica the resulting rocks if wholly crystallized would consist of orthosilcate of sodium and aluminium, nephelite; this with polysilicate of the same elements, albite; albite alone; or albite and quartz, according as silica is lower or higher. We may say the rocks would lie on the curved line *QAN*. The point *Q* is where pure quartz occurs; and the point *A* where pure albite occurs; and *N* where soda-nephelite occurs. Pure albite rock would occur at *A*. Any rock on the line between *A* and *N* would consist of albite and soda-nephelite in proportions varying from one extreme to the other. Any rock on the line between *A* and *Q* would consist of albite and quartz in proportions varying in the same manner.

From *A* as a point of departure let us consider what must be the composition of soda-alumina rocks not occurring on the line *QAN*. If we consider magmas with constant alkali-silica ratios, namely .166, it is evident that proceeding from *A* horizontally, as the silica percentage becomes less, the soda and alumina must also become less, consequently the sum of these constituents will not be 100, which is always the total of the percentages in any case. There must therefore be other chemical constituents besides Na_2O, Al_2O_3 and SiO_2. The same is true if we proceed from *A* vertically downwards, that is, if we consider magmas having the same silica percentage, namely 68.7, for with decreasing alkali-silica ratios there will be less soda and alumina, and the sum of Na_2O, Al_2O_3, SiO_2 will not be 100. The same will be true if we proceed in any direction from *A* below the line *QAN*.

All rocks except those occurring upon this line must contain other constituents than Na_2O, Al_2O_3, SiO_2. These may be CaO, MgO, FeO, Fe_2O_3 (potash being excluded by the initial assumption). Let us assume them to be either CaO, MgO, FeO, singly or together, and that they occur as silicates. The case of $FeO.Fe_2O_3$, magnetite, will be considered subsequently. It having been assumed that alumina is present only in proportions to satisfy soda, the possibility of the formation of an aluminous molecule with these constituents will be excluded for the

present. The silicates capable of forming from CaO, MgO and FeO are orthosilicates and metasilicates; olivine, $2(Mg,Fe)O.SiO_2$, with its theoretically possible extremes $2FeO.SiO_2$ (fayalite) and $2MgO.SiO_2$ (fosterite); orthorhombic pyroxenes, enstatite, $MgO.SiO_2$, and hypersthene, $(Mg,Fe)O.SiO_2$, and the monoclinic pyroxenes, diopside, $CaO.MgO.2SiO_2$, and salite, $CaO.(Mg,Fe)O.2SiO_2$. It is possible to introduce into the composition of a magma such as already postulated one or more of these molecules in such proportions as to make the sum of all equal to 100. But it is clear that the development of a silicate of any of these kinds in the magma would affect the distribution of the silica among the other molecules, that is, it would affect the relative porportions of albite and nephelite or of albite and quartz. It is possible to discover by simple algebra what would be the range of percentages of silica and the range of the alkali-silica ratio for a series of rocks composed wholly of albite and any one of the calcium, iron, magnesium molecules just mentioned. This range will be expressed by a curved line on the diagram extending from the point *A* to the point corresponding to the locus in the diagram of the pure molecule under consideration. Several of these lines are indicated on Diagram 1. The most extreme case, most favorable to the presence of albite is that in which it occurs in combination with $2FeO.SiO_2$, orthosilicate of iron. The range is indicated by line *AFa*, which shows the alkali-silica ratios necessary in order that a rock should consist wholly of albite and Fe_2SiO_4. Any rock occurring above this line and containing only the constituents $Na_2O=Al_2O_3$, FeO, SiO_2 would have relatively too little silica to form albite out of all the soda and alumina and would contain some nephelite. That is, all rocks of this kind occurring above the line *AFa* would carry nephelite, even those having alkali-silica ratio $=.03$, if $SiO_2 = 31$. Conversely, all rocks occurring below this line would have relatively too much silica to convert all the soda and alumina into albite and there would necessarily be quartz, if FeO alone formed an orthosilicate, which is the case in hand. Quartz would thus be a necessity in rocks with

only 35 per cent of SiO_2 when the alkali-silica ratio is less than .045. For a combination of albite and $2MgO.SiO_2$ the range is shown by the line *AFo*, and for a combination of albite and olivine, $2(Mg,Fe)O.SiO_2$, in which Mg: Fe:: 3:1, the range is *AOl*. From this it is seen that if orthosilicate of magnesium accompanies that of iron the nephelite limit will advance toward the left, that is, in the direction of higher silica percentages, and the quartz limit will recede in the same direction.

In case iron and calcium or magnesium occur as metasilicates the range of possible combinations of these with albite is shown by the lines *AF*, *AC*, *AM*. If magnesium and iron occur together in equal proportions, as in some hypersthene, the line nearly coincides with *AC*. So also if the metasilicate has the composition $CaMgFeSi_3O_9$, or $Ca_2MgFeSi_4O_{12}$ (a diopside) or $Ca_2Fe_3Mg_3Si_8O_{24}$ (actinolite molecule in amphibole) the range would coincide with the same line. An increase of magnesium would move the line to the left toward *AM*. The range of positions for diopside is indicated by the bracket in the diagram. The range of positions for enstatite would lie to the left of this for the most part. From this it appears that rocks having soda and alumina in equal amounts together with metasilicates of iron, magnesium and calcium, if they occur to the right of the limits just described would necessarily contain nephelite, and if they occur to the left of these limits they must contain quartz. Since metasilicates are the highest silicate of these elements occurring in igneous rocks it follows that no other ferromagnesian molecule may be postulated which will appropriate more silica from the magma. Hence the most favorable case, namely that involving the highest silicate of alkali and alumina and the highest of calcium, iron, and magnesium, requires the presence of quartz in all holocrystalline rocks occurring to the left of these lines. In actual fact the three elements just named usually occur in somewhat similar proportions, so that the position of the line *AC* represents the limit of quartz in the ordinary case most favorable to its scarcity. Any combination of orthosilicate will tend to move

the quartz limit still further toward the right, in the direction of lower silica percentages. Quartz must therefore occur in rocks with lower and lower silica in proportion as the alkali-silica ratio decreases, and as lower silicate molecules are developed instead of higher silicates. The line *AC* is probably very near the highest limit of *no quartz* to be found in holocrystalline igenous rocks.

If any of the iron crystallizes as magnetite instead of combining with silica to form ortho- or metasilicates, silica will be liberated to form more albite out of nephelite, or to produce more quartz by the side of albite. The effect of the development of magnetite then is to shift the quartz-nephelite limit farther to the right, that is, toward lower silica percentages. In the case of rocks within the nephelite limit, the effect will be to decrease the nephelite and increase the albite. It may also react upon the ferromagnesian silicates when orthosilicates are present, permitting the liberated silica to convert some of the orthosilicates into metasilicates without materially affecting the relative proportions of the other constituent minerals.

In this connection attention may be called to the line *NFa*, which is the range of magmas composed wholly of nephelite and the orthosilicate of iron. It appears to be the limit toward which the highly sodic magmas tend, as may be seen in Diagram 1. Magmas low in alkalis associated with the eruptive iron ores lie beyond this boundary.

II. In order to discover the relations that would obtain for magmas in which *the alkali is wholly potash* when *alumina is present in amounts just equal to the potash*, we have to consider the range of positions for rocks corresponding to mixtures of quartz and orthoclase (potassium-aluminium polysilicate), and of orthoclase and leucite (potassium-aluminium metasilicate). This corresponds to the red line *QOL*. As already remarked in the previous paper, the lowest potassium-aluminium silicate among the feldspathoid minerals appears to be the metasilicate, leucite, and when potassium is found in rock-making nephelite it may be explained as in a metasilicate molecule mixed with the

sodium-aluminium orthosilicate. If we conduct the discussion in the same manner as in the previous case we should proceed from the point *O*, the position for a pure potash-orthoclase rock. At this point the alkali silica ratio =.166 and SiO_2=64.7. Rocks consisting of pure orthoclase and leucite will occur along the line *OL*; those composed of pure orthoclase and quartz along the line *OQ*. Rocks having an alkali-silica ratio of .166 and less than 64.7 per cent. of silica must contain some other constituents than $K_2O=Al_2O_3$ and SiO_2. The same is true for all rocks lying below the line *QOL*. The range of rocks that might consist of pure orthoclase and orthosilicate of iron is shown by the red line *OFa*, close to the corresponding line for soda magmas. All rocks occurring above this would necessarily contain leucite, all below it would contain quartz. The lines *OOl* and *OFo* represent the range for rocks consisting respectively of orthoclase and olivine, and of orthoclase and orthosilicate of magnesium. They also mark the limit of the quartz-bearing rocks of this kind on one side, and of leucite rocks on the other. The lines for rocks composed of orthoclase and metasilicates of iron, magnesium and calcium are *OF*, *OC*, *OM*. They are somewhat further from the corresponding ones for soda magmas than in the case of the orthosilicates. Comparing their positions with those of the corresponding lines for soda magmas, it is seen that the quartz limit is lower in the scale of silica percentages for potash magmas than for soda magmas. That is, other things being equal, quartz will occur in less siliceous potash rocks than in the corresponding soda rocks, the most marked differences being in rocks highest in alkalis.

The development of magnetite would have the same effect in shifting the quartz-leucite limits toward the right, that is, toward rocks with lower silica percentages as in the case of soda magmas. The line *LFa* is the range for magmas composed of leucite and orthosilicate of iron and seems to be the lowest limit for potash magmas, as stated on page 102 of this volume.

Magmas in which both soda and potash occur with equal

amounts of alumina would behave in a manner analagous to that just described for either extreme, the feldspars would be soda-potash polysilicates, with quartz or with leucite or nephelite. The lines indicating the range of combinations of feldspar and ferro-magnesian silicates would occupy positions intermediate between the corresponding lines for albite and for orthoclase. The quartz-leucite-nephelite limits would be nearly the same as before.

III. Let us now postulate the case of magmas in which the *alkalis control an equal amount of alumina* and in which *lime and additional alumina occur in the proportion of one to one* and *constitute orthosilicate, anorthite molecules*. First, let all of the alkali be soda. This case is illustrated by Diagram 2. As the relative proportions of the constituents, $Na_2O=(Al_2O_3)'$, $CaO=(Al_2O_3)''$ and SiO_2 vary, those rocks in which there is soda and no lime will consist of albite and quartz, or of albite and nephelite, and will occur along the line *QAN*, Diagram 2, as in the previous Diagram 1. All rocks occurring below this line will contain anorthite molecules in variable proportions. Pure anorthite rock will occur at the point *An*, where the alkali-silica ratio $=0$, and $SiO_2=43.2$. The range of rocks composed wholly of albite and anorthite in varying proportions will occur along the line *AAn*. They correspond to rocks each consisting of a feldspar of the albite-anorthite series. The points on this line at which particular mixtures occur, such as Ab_6An_1, $Ab_2\ An_1$, etc., are designated in the diagram. This line also indicates the range of rocks consisting wholly of soda-lime-feldspar. All rocks from magmas of this case, III, to the right of this line must contain nephelite in addition to these feldspars. All rocks to the left must contain quartz, the argument being the same as for magmas of cases I and II. Assuming that the feldspar present is always one corresponding to the particular combination of albite and anorthite molecules in the magma, we may discover the range of magmas consisting of combinations of each of these kinds of feldspar and quartz on the one hand, and of these and nephelite on the other. They are

indicated by the lines *QA*, *Qb*, . . *QAn* and *NA*, *Nb*, . . *NAn*, which also indicate the limits for magmas of this kind. None would be possible to the right of the line *NAn*, unless containing other elements than those already mentioned for this case, III.

Since within the boundaries *QNAn*, rocks may exist composed wholly of quartz and the feldspathic minerals mentioned, the presence of any ferromagnesian compound necessitates the diminution of some of the first-named constituents, and since the silica percentages and alkali-silica ratios are the coördinates by which comparisons are made, we may assume that the presence of ferromagnesian constituents affects the lime and its equivalent alumina. Let them be affected equally. The orthosilicate anorthite molecules may then be replaced in some uniform manner by non-aluminous ferromagnesian orthosilicates or metasilicates. If the anorthite molecules be replaced by orthosilicate of iron, Fe_2SiO_4, the varying results are indicated in Diagram 2. If wholly replaced by Fe_2SiO_4, the line *AFa* would represent the range of the resulting rocks composed of varying proportions of albite and Fe_2SiO_4. And the area *AFaAn* would be the range of rocks composed of varying proportions of albite and Fe_2SiO_4 and anorthite. The lines *bFa*, *cFa*, etc., indicate the ranges of rocks composed of Fe_2SiO_4 and Ab_6An_1, Fe_2SiO_4 and Ab_2An_1, etc. That is, ranges in which the character of the lime-soda feldspar is constant, but the proportions of Fe_2SiO_4 vary. The line *Ay* shows the range of rocks composed of albite, with varying amounts of anorthite and Fe_2SiO_4 in the proportion of 4 to 3. At the points b', c', d', etc., where this line intersects the lines *bFa*, etc., the rocks would consist of Fe_2SiO_4 and the feldspars Ab_6An_1, Ab_2An_1, etc. From this it is evident that as the molecules of anorthite are replaced by ferromagnesian molecules, the feldspars in a rock of any given silica percentage and alkali-silica ratio become relatively higher in albite molecules, that is, the lines *Ob*, *Oc*, etc., would shift farther from *QA;* more sodic feldspars would occur in rocks with lower alkali-silica ratios. There would be a similar movement of the lines *Nb*, *Nc*, etc.,

away from *NA*; more sodic feldspars would be found in rocks lower in silica.

If the anorthite molecules be replaced by orthosilicates of iron, or of iron and magnesium, less silica would be required than before, and the quartz limit would shift to the right. If they were replaced by metasilicates of iron, magnesium or calcium, more silica would be required, and the quartz limit would shift to the left. If both were developed together the quartz limit might remain nearly as before. If magnetite were developed the effect on the quartz limit would be still more marked, and it would be shifted still farther in the direction of lower silica percentages.

Second, let all of the alkali be potash. Assuming that in this case there would be two distinct kinds of feldspar present, potash-orthoclase and anorthite, the range of rocks consisting wholly of these two minerals in variable proportions would lie along the red line *OAn*, Diagram 3, and the line *QOL* would be the range of rocks of this kind free from anorthite. All rocks of this kind occurring to the right of the line *OAn* must contain leucite; all those to the left must contain quartz. The effect of replacing anorthite molecules by ferromagnesian molecules would be similar to that just stated for the albite-anorthite magmas; however, orthoclase not being combined with anorthite, would remain as before except where changes in the silica affected the orthoclase molecules by reducing them to leucite, or affected the leucite molecules by raising them to orthoclase. This would occur in the neighborhood of the line *OAn*.

Third, if soda and potash were both present, other things being the same as postulated in the general statement of case III, it is evident that the range of rocks that might consist wholly of feldspars, either pure albite, pure orthoclase, or pure anorthite, or any possible mixture of these, would be within the area *AOAn*, Diagram 3. This narrow area would be the boundary between the quartz range on one side and the leucite-nephelite range on the other. The effect on the albite-anorthite feldspar, whose character would be that previously indicated if

all the alkali were soda, by the partial replacement of soda by potash would be to render it lower in the scale toward the anorthite end, so that the amount of orthoclase would be increased and the accompanying lime-soda-feldspar would be more calcic. This is indicated in Diagram 3. As potash replaces soda, the extreme limit of pure alkali-alumina silicate would shift along the line *NL* toward *L*. When they are in equal amounts the limit would be at *P*. At the same time, the range of rocks consisting wholly of anorthite, with albite and orthoclase in equal proportions, would be indicated by the line *xAn*. The points *b'*, *c'*, *d'*, etc., on it are where the lime-soda feldspar would have the value of Ab_6An_1, Ab_2An_1, Ab_1An_1, etc. The red lines connecting these points with *P* on one side and with *Q* on the other represent the range of rocks composed wholly of these particular lime-soda feldspars and leucite-nephelite on the one hand, and of these feldspars and quartz on the other. The replacement of anorthite molecules by ferromagnesian ones will have the same effect as that just stated for each extreme of alkali-lime-feldspar magmas.

IV. There remains to be discussed the modifications that would be effected in the feldspathic magmas already postulated by the introduction of ferroaluminous molecules. These may be of two kinds: ferromagnesian-ferroaluminous molecules, appearing in pyroxenes and amphiboles, with the general formula $(Mg,Fe)(Al,Fe)_2SiO_6$; and alkali-ferroaluminous molecules, occurring in mica, amphiboles, and pyroxene. Among these are molecules free from ferric iron, and others free from aluminium. They are $KH_2Al_3Si_3O_{12}$, $(K,H)(Al,Fe)SiO_4$, $NaAlSi_2O_6$, $NaFeSi_2O_6$.

Let us first consider those free from alkalis. Upon the general assumption that the alkalis control an equal amount of alumina, the introduction of ferromagnesian-ferroaluminous molecules would demand an increase in the alumina over that necessary to satisfy the alkalis. This must take place at the expense of the ferromagnesian and calcium molecules in cases I and II, or at the expense of anorthite molecules, in case III.

Let us consider cases I and II. The molecule (Mg,Fe
Fe)$_2$SiO$_6$ is a subsilicate. The range of silica percentag
all manner of variations in its composition is from 29.
Mg Al$_2$Si O$_6$ to 20.54 for Fe Fe$_2$Si O$_6$. The molecule usu
more nearly the average of these extremes. The silica ra
indicated in Diagram 1 by the bracket, which shows tha
molecule requires less silica than the orthosilicate of iron
siderably less than olivine, and very much less than diops
enstatite. Its development, then, would extend the quart
and reduce the nephelite-leucite limit very considerably i
portion to its own amount. It may be stated that in gene
amount is quite subordinate to that of the ferromagnesian
and metasilicates. Its effect on magmas of case III,
anorthite occurs, would be of the same kind as the introduct
non-aluminous ferromagnesian silicates, but the degree
change would be greater in proportion to the number of
cules introduced.

Turning to the alkali-ferroaluminous molecules, it is
observed that one, (K,H)(Al, Fe) Si O$_4$, is well known
capable of appearing in igneous rocks of almost any che
composition in which its elements occur. Two others (
Al Si O$_4$, and Na Fe Si$_2$O$_6$ appear to occur in rocks with s
chemical composition, while the fourth, Na Al Si$_2$O$_6$, is les
known but may be supposed to be of wide occurrence in
amounts. The first belongs to biotite. If the ratio be
potassium and hydrogen varies from 1 : 1 to 1 : 2, and the al
ium and iron be supposed to reach their possible extr
from normal biotite to lepidomelane, the range in silica pe
age for this orthosilicate molecule would be from 29.07 to
which is indicated by the bracket in Diagram 1. The re
proportions of potash and alumina vary from 1 : 1 to 1
most instances. Sodium does not enter into the molecu
any considerable extent, the development of biotite then a
the potash-feldspathic molecules. In orthoclase rocks w
the quartz limit its development would reduce the amou
orthoclase molecules, and would change a polysilicate in

rthosilicate and liberate silica, increasing the amount of quartz r raising ferromagnesian orthosilicates to metasilicates. But he development of biotite would draw upon the ferromagnesian rthosilicate (Mg,Fe) SiO_3, reducing the amount that might be onverted into metasilicate. The quartz limit would then be hifted toward lower silica percentages. In orthoclase-leucite ocks, or leucite rocks without orthoclase, the development of his potash-ferroaluminous molecule would reduce the amount of these minerals and liberate silica, which would raise the netasilicate leucite to orthoclase. The effect would thus be o cause the leucite limit to recede toward lower silica perentage.

It has already been noted that the development of biotite nvolves, besides the potash-bearing molecule under discussion, n orthosilicate of iron and magnesium, which is the same as an livine molecule. The development of this molecule in rocks that night otherwise carry ferromagnesian metasilicate molecules vould still further liberate silica, to appear as more quartz or aise more leucite to orthoclase.

In case alumina is in excess of potash in this mica molecule he excess of alumina must be drawn from an excess of alumina ver the alkalis originally in the rock, or it must be drawn rom a sodium-aluminium molecule, since no potash molecule, n which potash exceeds alumina, occurs to any extent in the yrogenetic minerals according to present theories. In the econd instance the effect would be to reduce the albite or ephelite molecules and drive the soda into combination with erric iron, affecting the distribution of the silica.

The development of the metasilicate molecule, $NaAlSi_2O_6$, vhich enters amphibole, would reduce the albite molecules with he liberation of silica and the possible production of quartz, or he raising of nephelite to albite. It would reduce the nephelite nolecules if it did not affect those of albite, and would require dditional silica, which would have to be drawn from a polysiliate (orthoclase) or from a metasilicate. It does not appear to nter largely into the composition of rock-making amphiboles,

except possibly into those crystallized from magmas rich in soda and alumina.

The molecule (H,K) $Al Si O_4$, with little or no iron and with hydrogen and potassium, usually in the proportion of 2:1, occurs as muscovite. It is nearly identical with that occurring in biotite, except for lower iron. Muscovite occurs as a pyrogenetic mineral only in the most highly siliceous and quartzose rocks, where it is sometimes accompanied simply by quartz and alkali feldspar. The fact that this molecule often carries three times as much alumina as potash, and the absence of other potash molecules in which potash occurs in greater amount than alumina, indicates that the muscovite molecule develops in magmas in which alumina is in excess of the alkalis. Its presence bears no direct relation to the percentage of silica in the rock. Its absence from many rocks in which alumina is in excess of alkalis is probably due to its combination with iron and magnesia, resulting in the formation of biotite. Magmas sometimes occur with so large an excess of alumina that it crystallizes as corundum, Al_2O_3, in association with alkali-feldspars. The alumina in these cases did not enter muscovite molecules with the potash.

The development of the sodium-iron-metasilicate, $Na Fe Si_2 O_6$, which occurs in pyroxene, as the acmite molecule, and also in riebeckite, is pronounced in magmas rich in sodium and ferric iron; Fe_2O_3 appearing to take the place of Al_2O_3. Considered in connection with the composition of rocks of case I and III, Diagrams 1 and 2, its presence reduces the amount of albite, and increases the silica available for quartz or for raising nephelite molecules to albite according to the position of the rock in the scheme. Its presence would therefore shift the quartz limit toward lower silica percentages. It does not appear to play any considerable rôle in rocks low in soda or in ferric oxide.

It is not the plan of the present paper to discuss the effect on the mineral composition of rocks of the development of the less abundant or subordinate minerals. In some cases their production is clearly due to the presence of special elements,

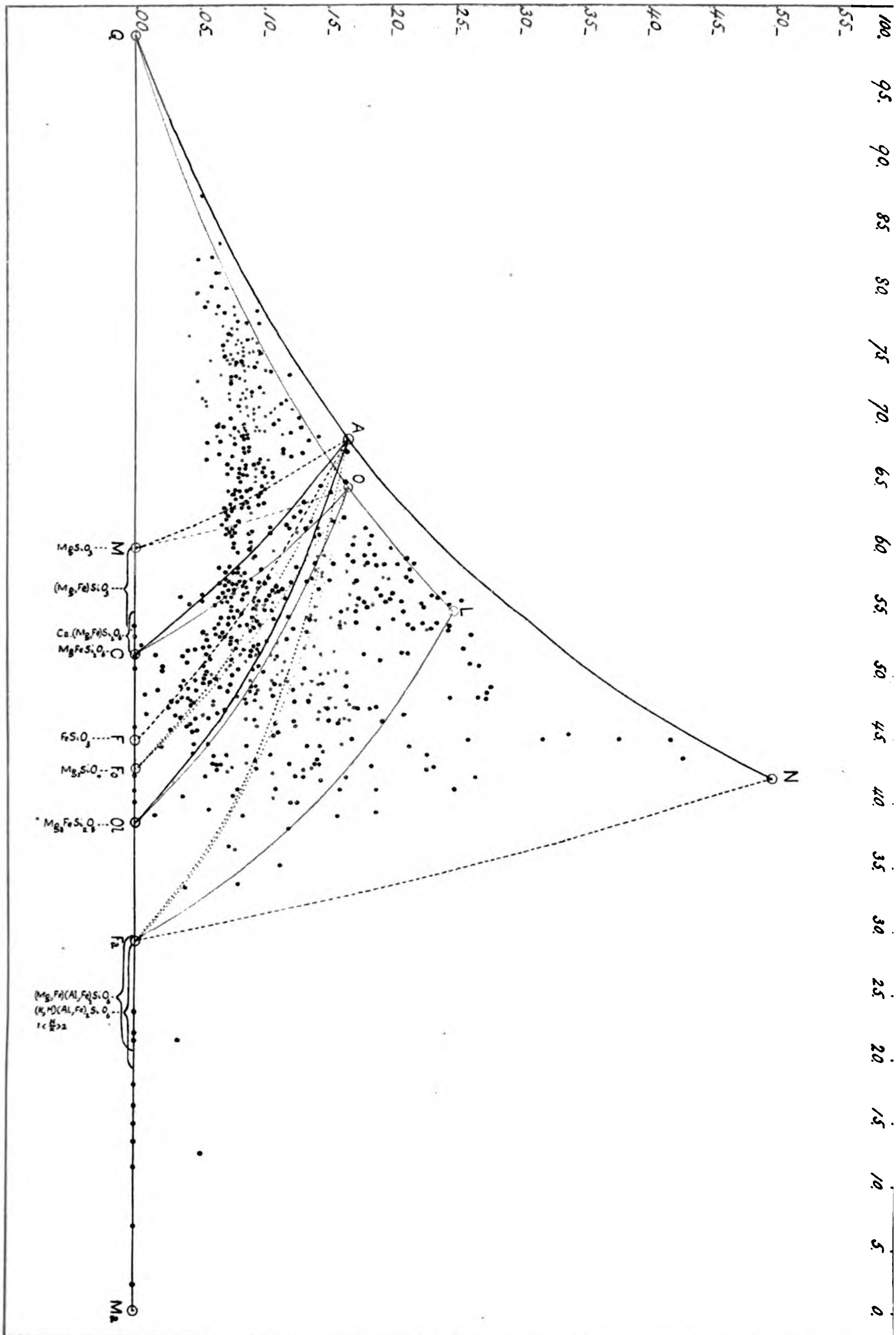
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DIAGRAM I.

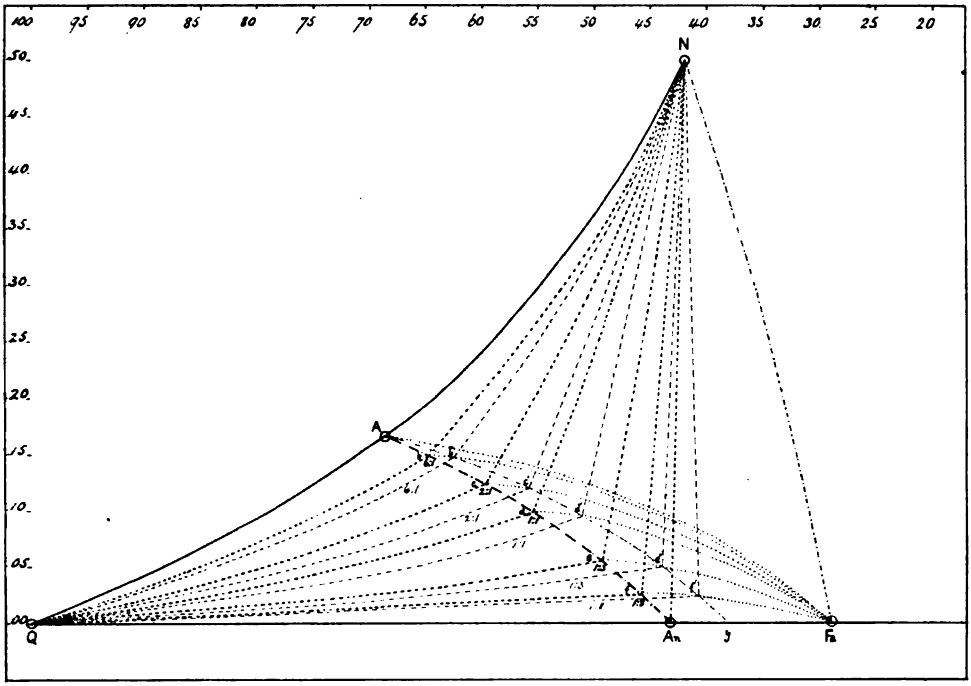


DIAGRAM 2

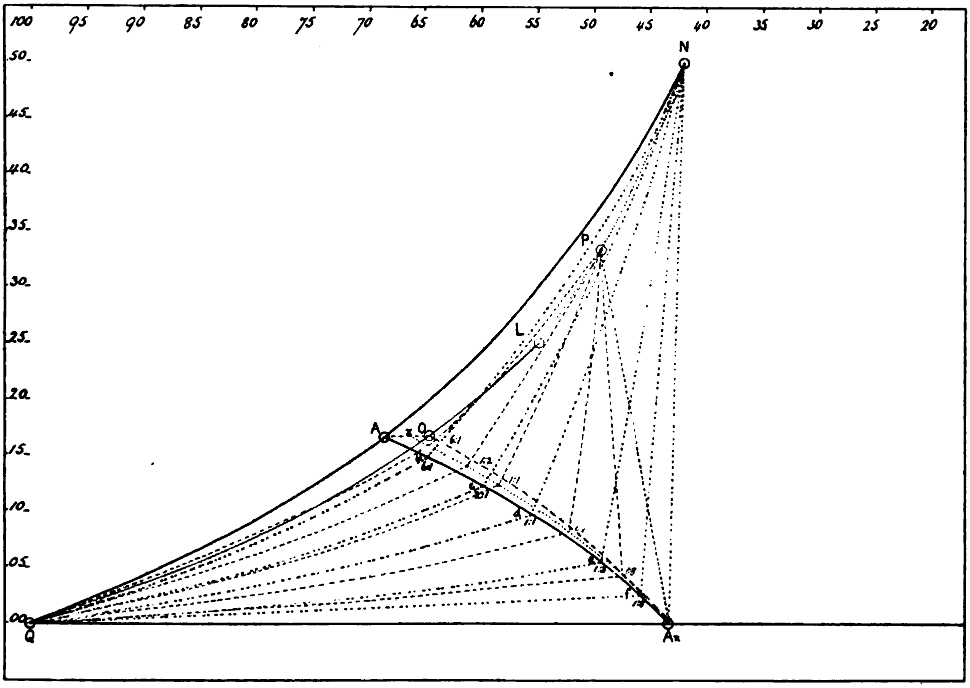


DIAGRAM 3

such as phosphorus, titanium, zirconium, sulphur, chlorine, fluorine, boron, etc., and their influence in modifying the proportions of the preponderant minerals is self-evident.

The discussion has been far from complete, but it is hoped that it may lead to a better understanding of the relations between the chemical and mineral composition of igneous rocks, especially the factors controlling the range of quartz on the one hand and of leucite and nephelite on the other. It certainly makes more evident the interdependence of the various minerals on one another and on the chemical composition of the magma. And it may possibly suggest lines of investigation that may contribute more substantially to our knowledge and conception of these intricate relationships. JOSEPH P. IDDINGS.

THE WEATHERED ZONE (YARMOUTH) BETWEEN THE ILLINOIAN AND KANSAN TILL SHEETS.[1]

PRELIMINARY STATEMENT.

THE full extent of the overlap of the Illinoian upon the Kansan has not been determined. It is certain that a sheet of Kansan drift underlies the Illinoian throughout its extent in southeastern Iowa, and in all probability it continues some distance eastward into western Illinois, in the section between Rock Island and Quincy.

There may be a sheet of Kansan age formed by the Illinois glacial lobe. The available data, however, do not place this beyond question. Occasional wells in central Illinois are reported to have passed through a black soil at some distance below the Illinoian till. But, so far as the writer is aware, no exposures of such a soil have ever been discovered. Professor Salisbury has collected data in southeastern Illinois and southwestern Indiana which support the view that there may be two distinct drift sheets in that region. It is his opinion that the upper or Illinoian sheet extends farther south than the lower sheet.[2] Whether the lower sheet is of Kansan age is still a matter for conjecture. It also is still an open question whether the drift of the east border of the driftless area in northwestern Illinois and southwestern Wisconsin is of Illinoian age or of earlier date. In view of these uncertainties this discussion of the Yarmouth weathered zone is restricted to the region where the Illinoian sheet of the Illinois lobe overlaps the Kansan sheet of an ice lobe lying farther west.

Numerous exposures of a soil and weathered zone have been observed at the junction of the Illinoian and the Kansan till sheets in the region of overlap between Davenport, Iowa, and

[1] Read before the Iowa Academy of Sciences, December 1897.

[2] Communicated to the writer.

Quincy, Illinois. The presence of this soil horizon was first rought to the writer's notice by a well section at Yarmouth in Des Moines county, Iowa. For this reason, and because the ame of this village is less likely to be confusing than names which are more common, it seems appropriate to apply the name Yarmouth to this weathered zone. There is also at Yarmouth ot only a soil horizon, but apparently a pronounced erosion etween the Illinoian and Kansan sheets.

THE YARMOUTH SECTIONS.

About ten years ago, Mr. William Stelter, of Yarmouth, owa, sunk a well near that village which passed through a bed f peat at the base of the Illinoian till sheet. The peat conained small bones which have been identified by Dr. F. W. True, of the United States National Museum, as (1) a portion f the pelvis and upper part of the femur of the wood rabbit (*Lepus sylvaticus*), and (2) the scapula of the common skunk (*Mephiticus mephitica*). The following section is based upon a tatement made by Mr. Stelter soon after the well was dug and pon specimens of the several classes of material penetrated, which were also furnished me for examination :

	Feet.
Soil and loess loam,	4
Yellow till (Illinoian),	20
Gray till (Illinoian),	10
Peat bed with twigs and bones,	15
Gray or ashy clay containing fragments of wood,	12
Fine sand,	16
Yellow sandy clay with few pebbles (Kansan),	33
Total depth,	110

One mile south of Yarmouth, on the farm of Mr. F. Smith, well was in process of excavation during a visit made by the writer to that region some years later, and the following section was determined by examination of the material in the dump, and with explanations by the well-borer. The well is located on a igh point on the ridge marking the border of the Illinoian

drift, perhaps 25 feet higher than the village of Yarmouth, which also stands on the ridge. It will be observed that the black muck penetrated in this well is at a level fully 40 feet lower than in the well at Mr. Stelters. This difference in level is interpreted to be due to one well having struck into a valley cut into the Kansan drift, while the other well entered the Kansan drift near the level of the bordering uplands.

SECTION OF WELL AT F. SMITH'S, NEAR YARMOUTH.

	Feet.
Yellow till (Illinoian), - - - - - - - - -	36
Sand with thin beds of blue clay and also of cemented gravel, - - - - - - - - - - -	73
Black muck containing wood, - - - - - -	6
Sand and gravel, probably alluvial, - - - - -	8
Gray silt nearly pebbleless, apparently alluvial, - -	15
Blue till (Kansan), - - - - - - - - -	42
Total depth, - - - - - - -	180

If my interpretation of the records at Yarmouth is correct, there is here not only a notable accumulation of peat and muck between the Kansan and Illinoian, but also an erosion of the Kansan till sheet to a depth of 40 feet prior to the deposition of the Illinoian. Since these sections are based entirely upon well records, they afford a less clear idea of the relation of the beds than might be afforded by valley excavation.

Exposures in neighboring districts. — One of the most satisfactory exposures yet found is that afforded by a ravine about one mile northeast of West Point, in Lee county. This was first seen by the writer in 1894. The following section may be obtained by descending the gully at the roadside:

	Feet.
Surface silt (loess), - - - - - - - - -	6
Black soil with ashy gray subsoil, - - - - -	5
Brown till containing many bowlders, among which were two red jaspery conglomerates (Illinoian), - -	15
Black mucky soil with gray subsoil (Yarmouth), -	6
Brown clay with few pebbles (Kansan), - - - - -	15
Total, - - - - - - - -	47

This exposure was visited by Professor T. C. Chamberlin and Dr. H. F. Bain in August 1896 and by each the black material beneath the till was considered a typical soil, and the gray material below a typical subsoil. The slightly pebbly brown clay beneath this subsoil shows no response with acid. Other exposures, however, have been found in which a response with acid may be obtained within six feet below the base of the lower or Yarmouth soil.

Between West Point and Denmark, a distance of seven miles, records of thirteen wells have been obtained in which a soil was found between the Illinoian and Kansan till sheets. The thickness of the soil ranges from 2 to 5 feet and its depth below the surface ranges from 16 to 45 feet; the usual distance to the soil is about 30 feet. This represents, therefore, the combined thickness of the Iowan loess and Illinoian till sheet. The loess, however, has a depth of but 5 to 10 feet. Of several wells made at Denmark in 1894 to 1897 the writer has witnessed the excavation, and finds that the leaching beneath the lower soil extends about 6 feet into the Kansan till sheet. One of the most satisfactory sections near Denmark is the following, made on the farm of Mrs. Van Tuyl:

	Feet.
Surface silt or loess of yellow color slightly calcareous and containing a few small pebbles near base,	7
Brownish yellow till, slightly calcareous and with few pebbles (Illinoian),	10
Brownish yellow till very pebbly and calcareous (Illinoian),	8
Blue clay with few pebbles (Illinoian),	10
Black mucky soil with wood (Yarmouth),	2
Brownish yellow till (Kansan),	12
Hard blue till (Kansan),	6
Limestone,	4
Total	59

In this connection it may be remarked that several of the wells in the vicinity of Denmark pass through 25 or 30 feet of oxidized Kansan till and enter rock without striking a blue till, but exposures in ravines both north and south of the villages

show a dark blue-black till thickly set with fragments of wood. This occurs at a level lower than the rock surface at Denmark and has a striking similarity to exposures in other parts of the state which are suspected to be pre-Kansan in age.

Exposures at Davenport, Iowa.—The Illinoian till sheet as above noted is known to overlap the Kansan as far north as Davenport, Iowa. There are excellent exposures of both sheets within the limits of that city and also at points a few miles west near Blue Grass. An exposure in Davenport on Eighth st. between Myrtle and Vine was discovered by Professor J. A. Udden and has been visited by Professor Calvin, Mr. Bain, and the writer, each of whom recognizes the presence of both sheets of drift and also the Yarmouth weathered zone. The surface of the Kansan till sheet has the appearance of slight erosion, for it shows a rise of about 15 feet in a distance of 20 or 30 rods. The Illinoian till sheet rests unconformably upon the eroded Kansan, reaching a lower level at the south end of the exposure than at the north. In making the descent along Eighth st. the following series of beds was found:

	Feet.
Loess, - - - - - - - - - - - - -	30
Weathered zone of reddish brown till (Sangamon), - -	3
Unleached brown till (Illinoian), - - - - - -	15
Weathered zone of gummy gray clay (Yarmouth), - -	3
Brown till changing to gray color, 12 to 15 feet (Kansan),	30

Exposures in Adams county, Illinois.—The most southerly exposures of the Yarmouth weathered zone yet observed are in Adams county, Illinois. In a ravine near Woodville in the northern part of the county two sheets of brown till appear which are separated by a gray gummy clay. This clay is thoroughly leached, while the till immediately above it is unleached. The latter has a thickness of only 10 or 12 feet. Another exposure was found at a well in process of excavation on a farm eight miles east of Quincy. This section is similar to that in the ravine except that the Illinoian till sheet has a thickness of 20 feet. Another exposure was found north of Payson near the

base of a ridge of Illinoian drift. The gray clay here rests upon a gravelly bed instead of a sheet of till, but appears to be of similar origin and age to the other beds referred to the Yarmouth stage.

Within a few miles south from this exposure the border of the Kansan drift emerges from the edge of the Illinoian and passes southward into Missouri. The driftless peninsula found by Professor Salisbury here sets in and occupies a narrow strip west of the Illinois from Pike county to the mouth of that stream,[1] beyond which the margins of the Illinoian and Kansan sheets take widely divergent courses. Fortunately there was sufficient overlap north from this driftless peninsula to make clear the interpretation that the Illinoian is a markedly younger sheet than the Kansan. This difference in age was suspected to occur from a comparison of maturity of valleys in the two districts, but the testimony of the weathered zone preserved below the Illinoian was necessary to confirm it.

FRANK LEVERETT

DENMARK, IOWA.

[1] See Proc. A. A. A. S., Washington meeting, 1891, pp. 251–253.

THE PEORIAN SOIL AND WEATHERED ZONE (TORONTO FORMATION ?)[1]

THE interval between the Iowan and Wisconsin stage of glaciation has been provisionally named Toronto by Professor Chamberlin, because of excellent exposures of interglacial fossiliferous beds along the Don Valley in Toronto, Ontario, which may prove to have this age.[2] Professor Chamberlin remarks in connection with the introduction of this name that the grounds for this correlation are not very strong, and further investigation may show them to be erroneous, but that it is not likely that the beds upon the Don can be referred to any earlier period. He further remarks, that, "Whether the beds on the Don belong to the horizon suggested or not, it is certain that vegetal beds were formed in the interval of the retreat between the formation of the Iowan till and the formation of the Wisconsin till, and some of these less well developed and less known deposits must be looked to as a type of this interglacial horizon if the Toronto beds prove unavailable."

In view of the uncertainty attached to this correlation, it seems advisable to employ for the present a substitutional name which is known to be applicable to the interval between the Iowan and the early Wisconsin. In case the correlation suggested by Professor Chamberlin is demonstrated to be correct the name Toronto has precedence.

Extensive deposits of muck and peat occur at the base of the Wisconsin drift in northern Illinois, notably in McHenry, Kane, De Kalb, La Salle, and Bureau counties, which are in all probability immediately underlain, in some cases at least, by

[1] This paper forms part of an unpublished report by the writer on the Illinois glacial lobe. It is published in connection with the two papers read before the Iowa Academy because of the close relation of the subject-matter.

[2] Classification of American Glacial Deposits, by T. C. CHAMBERLIN, JOUR. GEOL., Vol. III, 1895, pp. 270–277.

[I]owan drift. In central and western Illinois the soil is in places [u]nderlain by a fossiliferous silt, referred with some confidence [t]o the Iowan loess. In eastern Illinois the Iowan till may be [p]resent. This soil horizon, together with lower soil horizons, [w]as discussed by the writer in a paper presented at the Cleve[l]and meeting of the American Association for the Advancement [o]f Science.[1] At that time the separation of the Iowan sheet [f]rom the Illinoian had not been made and all the soils were [r]eferred to a single horizon. The later developments have led [t]he writer to separate the soils found at, or slightly below, the [W]isconsin drift into two classes—one class being thrown into [t]he Sangamon stage, while the other is thrown into the stage [u]nder discussion. It is not possible in all cases to decide to [w]hich class a buried soil should be referred, for in some cases [i]ts existence is known only through well records. The separa[t]ions thus made are set forth in detail in a report by the writer [y]et unpublished.

In selecting a name for the horizon, the ideal locality would [b]e one in which the earliest sheet of Wisconsin till overlies the [I]owan till. In the vicinity of Marengo, in McHenry county, a [b]lack muck has been found at the base of the Wisconsin drift, [a]nd it apparently rests on Iowan till. This might be taken as a [t]ype locality were it not that the Wisconsin drift at that point may not include the Shelbyville or earliest Wisconsin sheet of till. The same objection may be urged against buried soils found in Kane, De Kalb, La Salle, and Bureau counties, for in all these counties the outer Wisconsin ridge appears to be the Bloomington moraine, and the limits of the Shelbyville may be to the east of this ridge. It has seemed advisable, therefore, in the selection of a type locality to pass to central Illinois, where the Shelbyville sheet extends beyond the later sheets of Wisconsin drift. This, unfortunately, carries us beyond the Iowan till, but the loess, whose deposition seems to mark the close of the Iowan glaciation is there well developed. The interval between the loess and Shelbyville till sheet probably marks as

[1]For abstract of paper see Proc. A. A. A. S., 57th meeting, 1888, pp. 183–184.

well the time between the culmination of the Iowan and Wisconsin glaciations as if taken where the Shelbyville sheet overlies Iowan till.

The loess has been traced back in valley exposures several miles beneath the Shelbyville till sheet in northern Tazewell county, Illinois, and beneath the combined Shelbyville and Bloomington sheets in Woodford and Bureau counties. Farther south it has been recognized in well sections in southern Tazewell, northeastern Logan, western De Witt, southern Macon, and western Sullivan counties, Illinois. The phase of loess known as white clay has been traced several miles up the Kaskaskia and Embarras valleys in Shelby and Coles counties beneath the Shelbyville till sheet.

Of the several exposures those east of Peoria in northern Tazewell county are the best displayed. Decisive evidence is also found at these exposures of an interval of some length between the deposition of the loess and the deposition of the overlying Shelbyville till sheet. In view of these conditions in the vicinity of the city of Peoria it has seemed appropriate to apply the name Peorian to the interval between the Iowan loess and the Shelbyville till sheet, a till sheet which appears to be the earliest of the Wisconsin series.

In exposures along the T. P. & W. R. R., east of Peoria, and also on the east bluff of the Illinois opposite that city, the Shelbyville sheet is underlain by a bed of fossiliferous loess, similar to that found on the surface of the Illinoian outside the limits of the Shelbyville drift sheet, both in texture and in age. The loess is 8 to 12 feet in thickness, or about the same as on the uplands outside the Shelbyville sheet. It occurs at a corresponding elevation of about 200 feet above the Illinois River. Beneath it there is exposed fully 100 feet of the older drift sheet.

The upper part of the loess to a depth of two or three feet presents a reddish brown color, and is thoroughly leached. The leaching extends usually to a depth of about six feet. But beneath that depth the loess is often calcareous. The Shelby-

ville till was found to be very calcareous immediately above the loess. The evidence of a weathered zone at the top of the loess is as clearly shown as at the top of the underlying Illinoian till and several exposures occur in which the two weathered zones may seem in vertical sections. It is probable, however, that such a zone would be developed more rapidly in the loess than in the till, because of the greater porosity of the former.

Evidence of an interval between the Iowan and early Wisconsin glaciations is found in the great dissimilarity in the outline of the two ice sheets. The outline is more out of harmony, both with the early Wisconsin and the Illinois, than the outline of those sheets with each other. The great extension toward the south border of the driftless area, both in the Iowa and Illinois lobes of Iowan ice is singularly out of harmony with both succeeding and preceding glaciations. The shifting of lobes involved in the change from the Iowan to the early Wisconsin can scarcely be assumed to have occurred in a brief interval. The moraine-forming habit of the Wisconsin and absence of distinct morainic belts in the Iowan also implies a change in glacial conditions that can scarcely be assumed to have taken place suddenly.

Evidence of an interval between the deposition of the Iowan loess and associated silts, and that of the Shelbyville till, is found in a change in the attitude of the land which resulted in a marked deepening of the valleys. There appears to have been a greater depth of excavation during the Peorian interglacial stage than during the Sangamon. The breadth of excavation, however, was reduced to but a fraction of that in the Sangamon stage. The amount of change in altitude can as yet scarcely be even conjectured, much less demonstrated, but its effects on the drainage are such as to support the view that it denotes a time interval of considerable length; a view which is also supported by the work accomplished in deepening the valleys. Comparing the work with substages of the Wisconsin it appears that the interval may not greatly exceed that between the Shelby-

ville and Bloomington ice advances. The Shelbyville sheet had apparently become channeled by streams prior to the Bloomington substage of glaciation to nearly as marked a degree as the channeling below the level of the loess effected in the Peorian stage of deglaciation. There is also a marked increase in the stream gradient, the Bloomington drift sheet being accompanied by a much more vigorous gravel outwash than that which accompanies the Shelbyville sheet. In the writer's opinion it is questionable if the interval between the Iowan and early Wisconsin invasions covers more than a comparatively small part of the time occupied by the intervals between the Iowan and Illinoian, and between the Illinoian and Kansan. The union of the several lines of evidence just cited would seem to support the view that it is longer than interglacial substages of the Wisconsin. The view of a brief interval between the Iowan and Wisconsin meets a strong objection, however, in the supposed attendant deposits at Toronto.

Turning to the Toronto formation it is found that a fossiliferous silt occupying a horizon between bowldery glacial clays has a fauna and flora which denote a climate fully as mild as at present characterizes that region.[1] In discussing this formation Dr. A. P. Coleman remarks that unless the Labrador gathering ground is shown to have stood much higher than at present it can scarcely be supposed that a widespread sheet of ice was maintained there, while oaks and maples and pawpaws flourished on the land and Mississippi unios in the waters within 400 to 500 miles to the southwest. In the absence of any evidence of such an uplift he concludes that the ice fields were completely melted during this interglacial epoch. Professor D. P. Penhallow remarks that the arborescent forms of vegetation in these interglacial beds are of species such as may now be found in the same region.

[1] See descriptions by DR. A. P. COLEMAN and PROFESSOR D. P. PENHALLOW in American Geologist, Vol. XIII, Feb. 1894, pp. 85–95. See also additional interpretation by DR. COLEMAN, in JOUR. GEOL., Vol. III, pp. 274, 622–645.

For description of fossiliferous beds at Scarborough Heights and other localities near Toronto, by DR. G. J. HINDE, see Journal of the Canadian Institute, April 1877.

The extent of deglaciation suggested by these beds, so far space is concerned, can scarcely be supposed to have been ceeded either by the Sangamon or the Yarmouth stage of glaciation. The Toronto beds constitute probably the most cisive evidence yet brought forward in support of an extenve deglaciation within the glacial period. The time involved ay reasonably be supposed to involve a portion of the glacial riod by no means small. Its rank should be as high as that any of the interglacial stages, even if less prolonged than me of the earlier stages of deglaciation. Should it be proved represent the interval between the Iowan and Wisconsin posits, as now seems probable, the evidences above cited, from e peripheral portion, may aid in determining its length, mely, the leaching and erosion of the Peorian stage. As yet e fauna and flora buried beneath the peripheral portion of the isconsin drift have received little or no attention. Possibly the aid of this line of study the question of correlation may settled.

FRANK LEVERETT.

A GEOLOGICAL SECTION ACROSS SOUTHERN INDIANA, FROM HANOVER TO VINCENNES.

INTRODUCTION.

DURING the field season of 1896 the Indiana University Geological Survey undertook to map, geologically and topographically, a section across southern Indiana, reaching from the Ohio River at Hanover on the east, to the Wabash River at Vincennes on the west. The strip of country mapped is 6 miles wide, 120 miles long, and is embraced in the row of townships numbered 3 north.

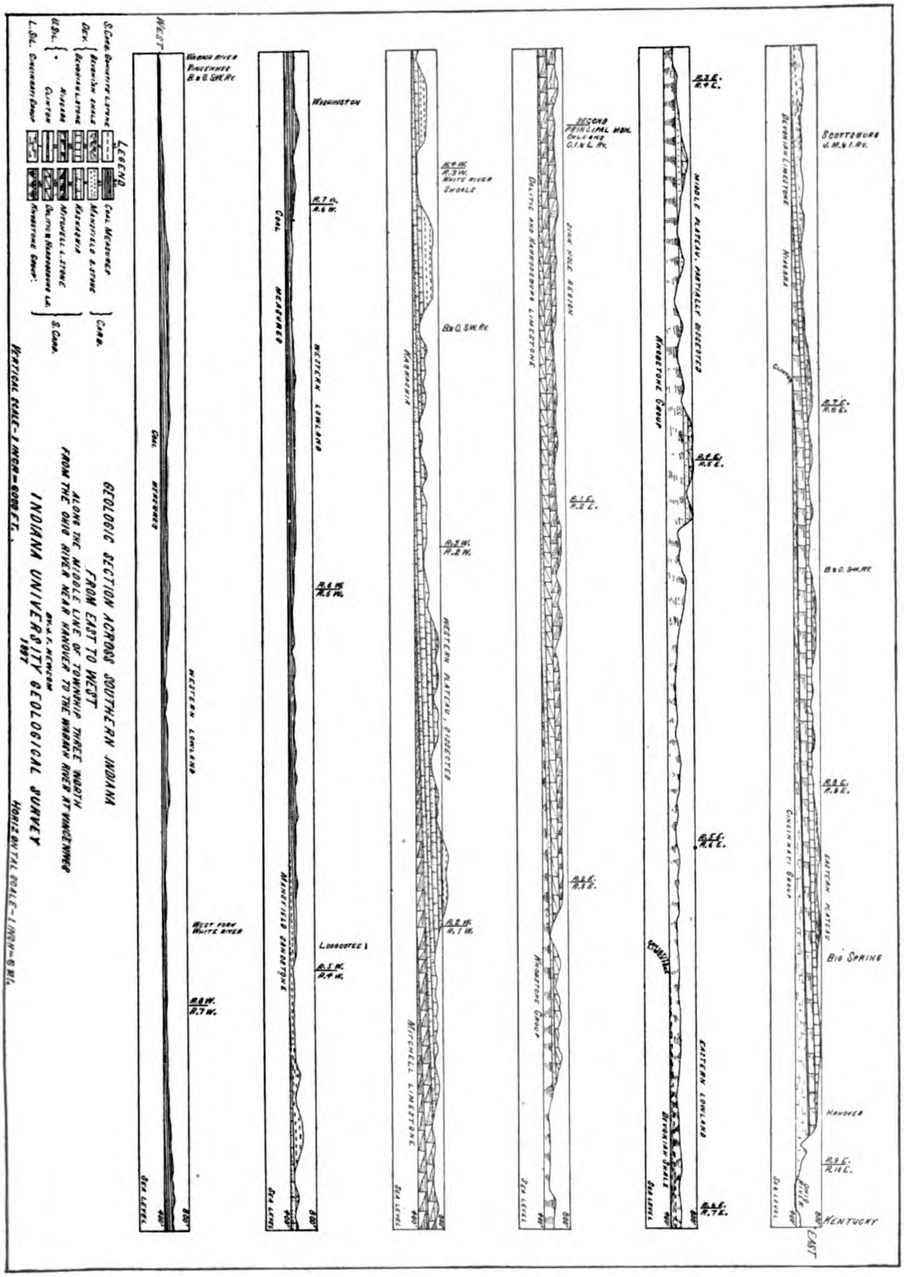
METHOD OF RUNNING THE SECTION.

The topographic work was done by means of aneroid barometers, with a line of levels through the territory by which the aneroid readings were checked. This line was run as far as Willow Valley station in Martin county, and as near the middle of the strip of country to be mapped as the conditions would permit; the elevations were obtained by means of the vertical arc, and are as accurate as the necessities of ordinary topography and geological cross sections demand. The line of levels was checked on the J. M. & I. and the B. & O. S.-W. R. R., where these roads were crossed. The dips of strata as shown by these levels may be depended upon within the suggested limits.

The section chosen was selected because the geological horizons and the topography crossed by it are typical of almost the entire southern part of the state. The geological horizons cannot be taken up here in detail, but it is desired to point out some of the relations existing between the topography and the geology.

THE HORIZONS CROSSED AND THE RESULTING TOPOGRAPHY.

The eastern plateau.—Beginning in the east near Hanover, at the west side of township 3 north 10 east, the lowest rocks


GEOLOGIC SECTION ACROSS SOUTHERN INDIANA
FROM EAST TO WEST
ALONG THE MIDDLE LINE OF TOWNSHIP THREE NORTH
FROM THE OHIO RIVER NEAR HANOVER TO THE WABASH RIVER AT VINCENNES
INDIANA UNIVERSITY GEOLOGICAL SURVEY
1897
LEGEND
WEST
EAST
KENTUCKY

exposed in Indiana are the limestones and calcareous shales of the Cincinnati group. Near Hanover these beds have an exposed thickness of about 250 feet, reaching from near the tops of the bluffs along the Ohio River down to and below the level of that stream, which at this place is about 400 feet above mean tide. Overlying this series of soft strata are hard limestones belonging to the Clinton, Niagara, and Devonian (Corniferous). The combined thickness of these beds is about 180 feet.

The limestones resist the action of the weather, and owing to these hard, resisting strata above, and the soft, easily eroded strata below, the conditions are favorable to the formation of bluffs and waterfalls. So it happens that each short stream that flows eastward into the Ohio has the upper end of its gorge marked by a precipice or waterfall, varying in height from 40 to 90 feet.

When the top of the limestone is reached the country immediately becomes approximately level. The Devonian limestone is overlain by the Devonian black shale, and as this shale has no hard beds immediately overlying it, it does not produce a rugged topography. The dip of the Devonian limestone from Big Spring, township 3 north 9 east, section 16 to section 20, 3 north 8 east is 231 feet, or a little over 33 feet to the mile. This dip is not constant, but varies from 20 to 46 feet per mile, and is in every respect sufficient to cause the westward flow of the streams.

In the eastern edge of Scott county the westward dip of the Devonian limestone and the overlying Devonian black shale is probably at its minimum; the hills of this locality, and the exposures of limestone in the valleys, are probably due to this structural feature. While the hills are not high—ranging from 50 to 100 feet above the valleys—they nevertheless form the most marked topographic feature between the Ohio River and the Knobs.

The Devonian limestone finally passes beneath the drainage near the west line of township 8 east, the country immediately

to the west becomes more gently rolling, and the low hills are made up of black shale covered over in most cases by glacial material.

The Devonian black shale outcrops over a strip of country some twelve miles wide. Except at its eastern edge where it has been eroded to a feather edge, and where the underlying limestone controls the topography, it forms very low hills, and often almost flat plains. The black shale passes beneath the drainage near Scottsburg. In a deep well drilled at Scottsburg its thickness was found to be 120 feet.

The eastern lowland.—Overlying the Devonian black shale is the Knobstone group of clay shales, sandy shales, and sandstones. The lower limit of this group is marked by the Rockford Goniatite limestone, which, owing to its thinness has but little effect on the topography. The lowest beds of the Knobstone group are made up of clay shales. These clay shales, with the underlying Devonian black shale, are directly responsible for the low country and very gentle topography to be found throughout southern Indiana, between the high escarpment known as the Knobs, and the deep gorge of the Ohio River. The western part of this region may be properly styled the eastern lowland.

One noticeable feature of the topography from the top of the escarpment near Hanover, where the elevation is 800 feet above tide, to Scottsburg (570 feet above tide), is the gradual westward slope of the country, corresponding almost exactly to the average dip of the strata. The tops of the low hills of this region are all found in approximately the same slightly westward dipping plain.

The "Knobs" and the middle plateau.—The Knobs form by far the most important topographic feature in the eastern part of the extreme southern portion of Indiana. They are made up of Carboniferous strata belonging to the "Knobstone group" with its capping Carboniferous limestones. The Knobs do not form a range of hills, properly speaking, but are rather a high escarpment, generally facing eastward, with a plateau sloping

very gently to the west, and with outliers to the east. The geological conditions, so far as they bear upon topography, are very similar to those along the Ohio River, to the east, *i. e.*, a thick series of soft and unresisting strata is capped by sandstone and more resisting limestones, thus making possible bold hills and steep slopes.

The parting between the Knobstone and the overlying limestone is not a sharp one, but is made up of interstratified limy and sandy layers, indicating a gradual change in the conditions of sedimentation. The easternmost point in the line of parting between the Knobstone group and the overlying limestone is at the southeast corner of section 18, 3 north 5 east. Passing on westward the top of the Knobstone is found lower and lower in the hills, until it finally passes beneath the drainage in the northeast quarter of section 19, 3 north 3 east, at an elevation of 537 feet, or 342 feet lower than its outcrop, just eleven and one-half miles east. This shows a general westward dip averaging about twenty-six feet per mile.

The sink hole region.—Overlying the Knobstone group, and still dipping to the west are the Harrodsburg and Mitchell limestones (of Hopkins and Siebenthal), and the Kaskaskia group, all belonging to the Lower Carboniferous. In the region of its easternmost exposure the limestone is very thin, being eroded to a feather edge. Passing westward from its easternmost exposure, it is found lower and lower in the hills, because of its westward dip, and the country becomes accordingly less rugged and takes on the gently rolling and pitted sink hole character common in limestone regions.

In this region and on westward across the outcropping Mitchell limestones, and until the Kaskaskia beds are reached, the country has a very gentle westward slope. This is less, however, than is to be found east of the "Knobs," and it is also less than the dip of the rocks; this is due to the fact that the limestones do not weather so easily as do the shales.

There is a noticeable increase in the size of the sink holes in going across the limestone region from east to west. The sink

holes at the eastern edge are rarely more than 20 feet deep and 200 yards across, while in the western part they are sometimes miles in length and from 50 to 200 feet deep, forming valleys, similar in every respect to ordinary valleys of erosion, except that they have no surface outlets for their drainage. The increase in the size of the sink holes is, of course, due to the greater thickness of the underlying limestone.

The western edge of the Mitchell limestone is found just west of the second principal meridian, where, overlying it, is the lower Kaskaskia limestone, a hard, close-grained, resisting bed, which is in turn overlain by a series of limestones and sandstones. The effect of these beds upon the topography is quite noticeable. The hills rise higher and higher to the west, until on the western edge of Lawrence county, where they are capped by the highest beds of the Kaskaskia group, they are from 100 to 250 feet above the valleys. Many of these valleys are only large sink holes, and have no surface outlets.

The Mansfield sandstone, or western plateau.— Overlying the Kaskaskia beds is the Millstone grit (Mansfield sandstone of Hopkins) or the sandstone that forms the lowest member of the Upper Carboniferous. This sandstone controls the topography in the region in which it forms the surface rock, and is, in the main, responsible for the high hills of Martin county. It has a gentle westward dip and owing to this fact the highest hills of the region are found near its eastern limit. The hills decrease in height with the dip of the rocks to the west. The resulting topography is essentially that of a thoroughly dissected plateau.

The western lowland.—The Mansfield sandstone is finally lost to view at the western edge of Martin county, a short distance east of Loogootee. West of this point the country is level, or very gently rolling. There is here an abrupt transition from the rugged hills capped with sandstone, in Martin county to the much lower, level country underlain by coal-bearing shales and sandstones at the east side of Washington county.

Overlying the Mansfield sandstone, and extending from its upper limit to the west line of the state, the country is underlain

by the coal-bearing shales and sandstones of the Upper Carboniferous. These beds are easily attacked by eroding agencies, and have, therefore, already been worn down very near to their base level of erosion (if, indeed, they have ever been high above that level), leaving a comparatively level flat country. This region is covered with more or less glacial material.

The accompanying profile section shows clearly these different topographic features, and also the relations between the topography and the underlying strata.

CONCLUSION.

In conclusion, attention should be called to the following points:

a. In passing from east to west across southern Indiana, three prominent topographic features are crossed, and these features are the results of combinations of strata as follows: (1) the high eastward escarpment along the Ohio River caused by a thick series of easily eroded calcareous shales overlain by thick and resisting limestones; (2) the high eastward-facing escarpment with its outliers to the east, known as the "Knobs." This escarpment is the result of a thick series of soft clay and sandy shales, protected by sandstones and resisting limestones. Along the line under discussion this escarpment is twenty-eight miles west of the escarpment along the Ohio; (3) the high hills of Martin county, which are the result of a series of limestones and sandstones capped by more resisting sandstones and which do not rise as an escarpment from the east, but become gradually higher, owing to the resisting nature of their lowest beds. The distance from the Knobstone escarpment to the highest hills capped with the Mansfield sandstone is about thirty miles.

b. The structure of each of these topographic features where crossed by the section is essentially the same in different stages of development, *i. e.*, that of a dissected plateau, sloping gently to the west. In the eastern, or the Devonian limestone plateau, in the region of Ohio, dissection has scarcely begun, as none except the streams flowing directly into the Ohio have deep

gorges, and these are only from one-half to one and a half miles long; in the middle, or Knobstone plateau, dissection has progressed much further than in the eastern one; while the western or Mansfield sandstone plateau has been completely dissected by its streams.

It is possible that this peculiarity in the amount of erosion that has taken place in these different plateaus is the result of the character and former upward extension of the overlying formations in each case.

c. The top of the eastern plateau where crossed by the section is 800 feet above the sea, that of the middle is 820 feet, and that of the western 880 feet above tide, while but a short distance to the north or south the topographic sheets show the elevations of these plateaus to correspond even more closely.

These closely corresponding elevations point strongly to the conclusion that the present topography of southern Indiana has developed from an old base level; a former plain of deposition, or a combination of the two, might, however, have given rise to the present conditions.

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NOTES ON THE OHIO VALLEY IN SOUTHERN INDIANA.

INTRODUCTION.

In recent years much work has been done on the streams and abandoned stream channels leading through or from glacial regions. The upper Mississippi, the Illinois, the lower Missouri, many smaller streams in Minnesota, Wisconsin, Illinois, and Iowa, the Wabash, and the upper Ohio have been examined more or less carefully, but on the lower Ohio, and more particularly that part between the falls at Louisville and the mouth of the Wabash, little or nothing has been done.[1]

The present paper deals with a portion of this unexamined region in Spencer county, Indiana. Spencer county is in the southwestern part of Indiana. With reference to the Ohio, it is about 130 miles below the falls at Louisville and 95 miles above the mouth of the Wabash.[2] The region is particularly interesting, because it is near the middle of the base of the unglaciated triangle of Indiana.

The following paper will discuss (1) an old cut-off of the Ohio, (2) a series of river sands and gravels which seem to be Tertiary, (3) a probable extension of the Lafayette sea up the Ohio valley, (4) peculiarities of the loess on the bordering hills, including an apparent twofold character of the loess, and (5) a record of continental oscillation furnished by the deposits at this point.

The three physiographic regions.— Physiographically, Spencer county may be divided into two parts, a plain and a hill region. The plain may be subdivided into three parts. First, a broad,

[1] Jour. Geol., Vol. III, "Preglacial Valleys of the Mississippi," by Frank G. Leverett, pp. 745 and 759.

[2] For general location see Figs. 1 and 2. Enterprise is in the western part of the region described.

level plain extends southwest along the western boundary of the county. It has the same general trend as Little Pigeon Creek, and will therefore be called Pigeon Plain, although this valley is not now occupied by Little Pigeon Creek.[1]

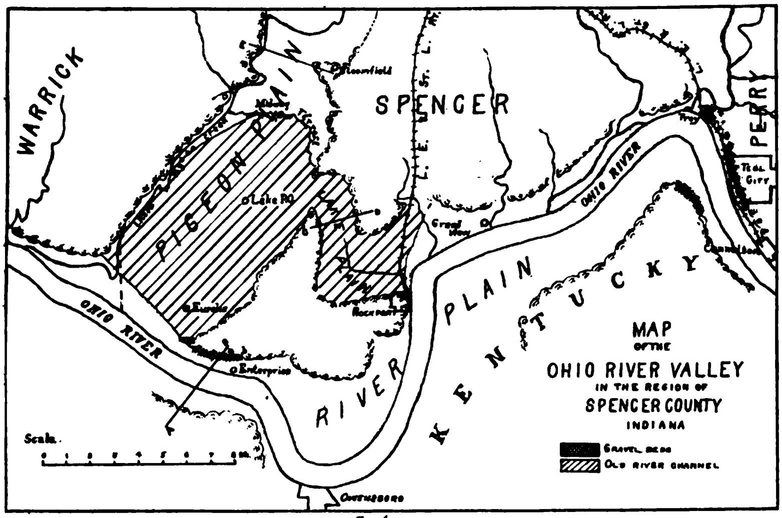


FIG. 1

Pigeon Plain is naturally divided into two portions by a terrace about fifteen feet high, which begins near the point where Lake Plain joins it, and extends in a general northwesterly direction past Midway to Little Pigeon Creek (Fig. 1). The plain north of this line is about fifteen feet higher than the portion south. The soil north is a reddish clay in part of the region and a very black peaty soil in the other; while the soil south is entirely different, being the same as that which makes the river bottoms and the River Plain, into which it merges at its south end. Other differences between the northern and southern parts of Pigeon Plain will be mentioned later.

Where Pigeon Plain enters the northern part of the area under consideration it is about two miles wide. It gradually

[1] The separation of Pigeon Plain and the valley of Little Pigeon Creek is not shown.

widens until at Midway it is about four miles and at Lake P. O. five, at which width it continues until it enters the second division of the plain region, the River Plain of the present Ohio.

The average width of the River Plain is between four and

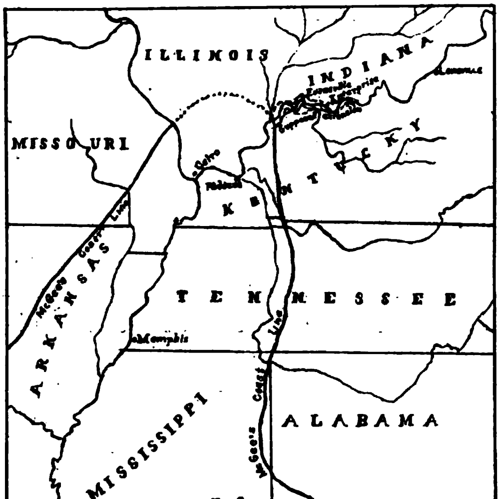


Fig. 2

MAP OF COAST LINE DURING THE LAFAYETTE ACCORDING TO McGEE, SHOWING ALSO SUPPOSED EXTENSION UP THE OHIO VALLEY

five miles. That portion which lies in Indiana is very irregular on account of the meandering course of the river. It includes all land locally termed the river bottoms. Three and a half miles below Enterprise, River Plain merges into Pigeon Plain.

The third portion of the plain enters, or rather leaves, the River Plain between Grandview and Rockport (Fig. 1), its southern portion including part of the town of Rockport. It is here three miles wide, but soon narrows down to two miles. It extends westward three miles, where it turns abruptly northward, and there narrows to about one mile. After going three miles in this direction it turns westward again, and enters Pigeon Plain two miles east of Lake P. O. The narrow part of this plain was occupied by a shallow pond of water when this country

was first settled. This pond was called "The Lake" by the early settlers. For this reason this division may be termed Lake Plain, although the lake is a result and not a cause of the plain.

These three plains so merge into one another that it is impossible to tell where one begins and the other ends. The average level of the plain above low water in the Ohio at Rockport is about thirty-five feet. The difference in levels of all three is very slight, not being over twenty feet, except where trenched by modern channels. The surface is so nearly level that large portions of this county either are or were swampy.

The hill region occupies all land not occupied by the plains above outlined. It will be seen from the location and interconnection of these plains that the south part of the hill land is completely cut off from the north or main upland, and stands as a roughly triangular tract, with channels or low plains on every side.

This region is characterized by a great number of hills rising on an average from forty to sixty feet above the plain. The highest part of the triangular hill land is in Rockport, near the junction of Lake and River plains, where the hills rise 110 feet above the plain. The next highest is at the junction of Pigeon and River plains, where the hills reach the height of ninety feet; the bordering hills being in general higher than those in the interior and the hills on the south and east higher than those on the west.

The northern portion of the hill land is higher and more irregular. The highest point measured is about four miles north of Rockport, where one of the "Knobs" rises 240 feet above the general level of the plain, or 275 feet above the Ohio River at Rockport.

The loess.—The hills bordering the plains in the triangular hill land are all covered with loess. The southern border of the northern portion of the hill land is covered from Grandview as far as the point where Lake and Pigeon plains meet. From this point the loess follows the terrace mentioned above northwestward.

The region in the interior, in all the triangular hill land, and for a short distance north of the southern boundary of northern hill land is covered with typical interstream loess.

It follows in all of its details the characteristics of loess as given by Salisbury.[1] It is best developed along the hills bordering stream channels, where it has the peculiar yellow or yellowish buff loess color. Where exposed it weathers into perpendicular banks. As it recedes from the stream channels it becomes thinner and less characteristic. This change in thickness is accompanied by a change in color, so that in the interstream areas it so closely simulates residuary earth that it is impossible to tell where one begins and the other ends. In parts of the deposit, loess-kindchen are very numerous. They are of the same type as those described by Call in Arkansas,[2] which, according to his statement, differs from the typical northern loess-kindchen in being solid. Limonite tubes and concretions and immense numbers of very small land shells occur in some deposits.

The change from typical bluff loess to interstream loess is noticeable in passing northward from the terrace in Pigeon Plain. This peculiarity is of much assistance in working out the origin of the terrace.

The thickness of the loess along the border hills will average about 20 feet. The highest elevation of the loess above the plain is at Rockport, where it rises 110 feet. It was seen at places on the "Knobs" at heights of about 100 feet. In nearly all of the region it extends down to the level of the plains, and much of the plains is made of redeposited loess.

Along the eastern shores of Pigeon Plain this loess is interlaminated with a grayish sand in its lower portions. Along the edge of the hills, and parallel with them, are many lenticular sand hills ranging from 10 to 30 feet high.

[1] Ark. Geol. Survey, 1889, Vol. II, "On the Relationship of the Pleistocene to pre-Pleistocene formations of Cowley's Ridge," pp. 226–228.

[2] Ark. Geol. Survey, 1889, Vol. II, "Cowley's Ridge," by R. Ellsworth Call, p. 38.

The obstructed valleys.—All the valleys which come from the hill region into the plain along the line of hills on the western side of the triangular upland have a very abnormal character. At the points where the streams pass from the upland to the plain, two long ridges of loess and sand 20 to 40 feet high jut out from each side like the arms of a great dam. These two parts almost meet, and the stream passes through the narrow V-shaped space between them. These dams are continuous with the loess-capping of the hills, which is so regular here that it looks much like a great artificial embankment. Although these dams are best developed along this line of hills, a similar tendency to dam the mouths of valleys on the east and south sides of the triangular hill land is shown.

These peculiar loess dams must be taken into consideration in any theory accounting for the manner of deposition of the loess of this region. The fact that valleys have been found facing in all directions, seems opposed to a wind origin. A prevailing southwest wind blowing over dried mud flats in the River and Pigeon plains could have formed all the dams on the western side of the triangular upland, but could not have formed some of the others. For this reason it seems probable that the loess of this region was deposited on the bordering hills as a natural levee by the swollen waters of the river, and that the dams across the mouths of these valleys represent continuations of this levee.

Driven-well area.—In all the plain region bounded by these loess-capped hills, that is, all the River Plain, Lake Plain, and that portion of Pigeon Plain south of the terrace, excepting a very narrow strip in a few places along the base of the hills, wells reveal a great trench filled with an irregular series of clays and water-bearing sands and gravels. This is the region of the driven wells. In the hill region and most of the region in Pigeon Plain north of the terrace all wells strike rock at comparatively shallow depths.

At Rockport wells have been driven 70 feet in the river alluvium without reaching rock. The normal depth of wells in

middle Lake Plain and northern Pigeon Plain south of the terrace ranges from 17 to 40 feet. Very few wells are deeper, and only those near the bordering hills reach rock. One well, 56 feet deep in the narrowest part of Lake Plain, did not reach rock. In River Plain wells range from 30 to 60 feet in depth.

From these wells can be learned something of the original depth of this filled valley. If all sands, clays, and gravels which underlie Lake, River, and a portion of Pigeon plains could be removed, a valley extending at least 56 and probably more than 70 feet below the present plain level, and having its sides of middle carboniferous strata, would be shown.

The old cut-off.—This valley under Lake Plain and the southern part of Pigeon Plain is the same depth as the half filled Ohio gorge of which it is a continuation. It is filled with the same materials. The hills on each side are capped with typical river-bluff loess in the same manner as those on the erosion scarp of the Ohio. The levels of the plain are so nearly the same that a portion of the waters in the flood of 1884 flowed swiftly through Lake Plain and entered Pigeon Plain, where one part followed the terrace and then turned southward and met the other part, which flowed south of Lake P. O., joining the waters of the Ohio again where Pigeon and River plains meet. This stream was four feet deep at the junction of Pigeon and Lake plains.

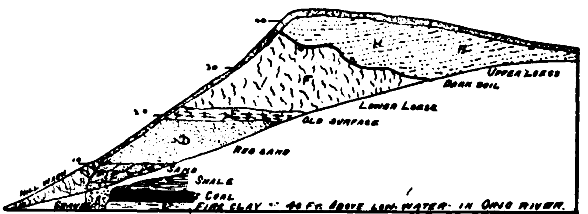
All these facts can lead to but one conclusion: The Ohio River at one time flowed through the Lake Plain and down through Pigeon Plain, entering the Ohio valley again between Enterprise and the eastern border of Warrick county.

To the erosive power of the river is to be attributed the greater part, if not the whole, of the gorge now occupied by that portion of the plain which has been called Lake Plain. In Pigeon Plain the work done was simply deepening and broadening on the eastern side of a broad valley extending from the northeast, which the river entered after cutting through the rock in Lake Plain. A portion of this more ancient valley, extending from the northeast, still remains intact north of the terrace, the terrace being simply the northern boundary of the Ohio's

downcutting in the older valley. The conspicuous differences in width which exist between various parts of the cut-off are to be explained by the fact that the river entered an old river channel when it came to Pigeon Plain. Nearly all the swampy areas mentioned above are simply parts of the old channel which have been but imperfectly filled.

An ancient valley from the north.—The ancient stream plain which the Ohio entered after cutting through the hills two miles east of Lake P. O., is locally called Pigeon valley; but, as has been stated, it is not at present occupied by Little Pigeon Creek. A cross section of the country from *E* to *F*, Fig. 1, shows Little Pigeon Creek in a young, V-shaped, rock-bound valley, separated by a hill of sandstone 30 feet high from the broad old alluvial-filled valley east of it (Fig. 12). Another section running east and west half a mile north of Midway shows the same peculiarities. Well sections in a few places west and northwest of Midway show a depression of 60 feet deep, fielld with blue mud.

Tertiary gravel beds.— Near the base of the hills north of Enterprise (Fig. 1) is a series of sands and gravels. The roads cut through these bounding hills at different places and afford admirable sections of the formations. A section examined along the road running between sections 3 and 4, township 8, south range 7 west, showed the following strata (Fig. 3):[1]



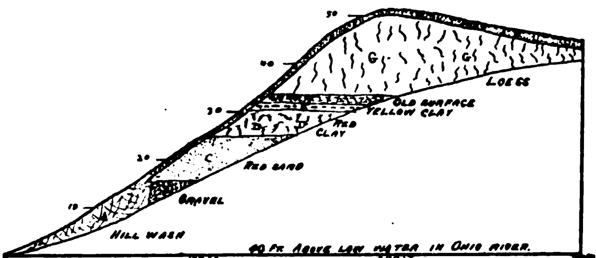
SECTION THROUGH BLUFF AT i, N.W. OF ENTERPRISE
FIG. 3

		Ft.	In.
A	Hill wash — a reddish sandy clay, - - - - - -	5	0
B	Coarse gravel mixed with sand. The gravel is mostly a much glazed dark yellow chert, but also contains some		

[1] The location of this section is shown at *i* in Fig. 2.

	white quartz and fragments of geodes — largest pebbles from 3 to 4 inches in diameter. A layer of gravel about 3 inches thick stained black with manganese occurs near the base of the part exposed,	1	6
C	White, yellow and orange sands cross-bedded. In one place pure white sand is 9 inches thick. Three layers of white sand occur directly above the gravel. The line between the sand and the next stratum D is not well marked, the one grades into the other,	3	6
D	Brick red sand,	9	0
E	A much stained clay, indicating an old surface,	2	0
F	A brown loam below turning into a typical loess above full of loess-kindchen	10–15	0
G	A thin layer of dark soil discolored with iron, producing below plates of iron one-eighth of an inch,	0	3
H	Loess grading into surface humus,	5–10	0
I	Surface humus.		

One mile east of the above the following strata were observed:

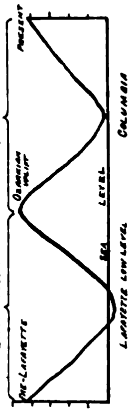


SECTION THROUGH BLUFF AT 1, N.E. OF ENTERPRISE
FIG. 4

SECTION 2. (FIG. 4).

		Ft.
A	Hill wash — a reddish sandy clay,	10
B	Gravel — coarse, well-rounded yellow chert, with a few white quartz and geode pebbles somewhat stratified. Streaked with manganese, which in places forms a conglomerate,	5
C	Reddish sand turning above to reddish clay flecked with white,	10
D	Very red clay mottled with black,	5
E	Yellow to drab clay showing white streaks,	2

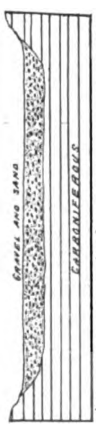
PARTIALLY IDEAL SECTION FROM A TO B FIG. 1 SHOWING VALLEY OF OHIO AT THE PRESENT TIME
FIG. 8



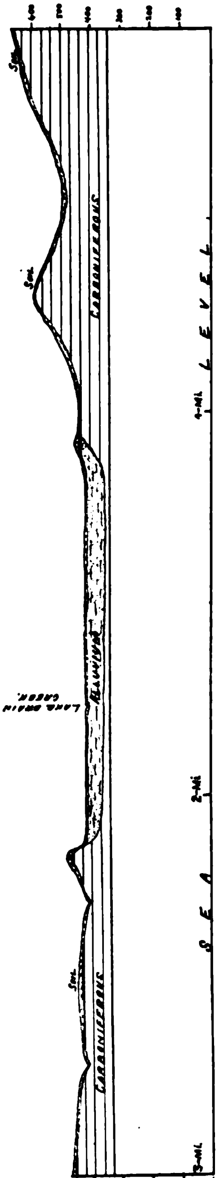
CONTINENTAL OSCILLATIONS OF OHIO VALLEY AT ENTERPRISE
FIG. 9

IDEAL SECTION FROM A TO B FIG. 1 SHOWING VALLEY OF OHIO AT THE CLOSE OF OZARKIAN UPLIFT
FIG. 7

IDEAL SECTION FROM A TO B FIG. 1, SHOWING VALLEY OF OHIO AT THE BEGINNING OF THE LAFAYETTE.
FIG. 5



IDEAL SECTION FROM A TO B FIG. 1, SHOWING VALLEY OF THE OHIO AT CLOSE OF THE LAFAYETTE.
FIG. 6

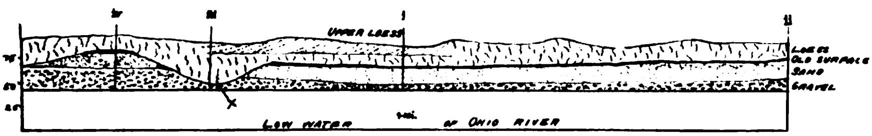


SECTION FROM C TO D FIG. 1, SHOWING FILLING OF CHANNEL IN LAKE PLAIN
FIG. 10

F	Mottled clay much weathered showing yellow, orange and black — evidently an old land surface,	3
G	Loess containing a few concretions,	15
H	Surface humus.	

One-half mile of section 1 (See *iii*, Fig. 11.) only a thin layer of gravel is found. At this place it is directly overlaid with loess full of concretions. The sands and clays which overlie it in the other sections are absent; but scarcely a quarter of a mile west on the same hill gravels and sands rise 35 feet above the plain (See *iv*, Fig. 11.) and about 70 feet above the river. The gravel here does not appear to be in any particular bed, although it is more abundant near the base of the hill. At times it is found in lenticular beds between the sands. Brick red sands were seen at a height of 35 feet. The pebbles in many places are cemented together, forming large masses of conglomerates. Through the sands are plates of iron as much as 3 inches thick. The old surface was visible but not very well defined.

One mile west of section 1, at *v*, Fig. 11, the following strata were observed:



IDEAL SECTION EAST AND WEST ALONG BLUFFS NORTH OF ENTERPRISE SHOWING UNCONFORMITY AND LOCATION OF SECTIONS DESCRIBED
FIG. 11

SECTION 5. (FIG. 11).

		Ft.
A	Gravel — same as that found in other section. Somewhat bleached,	20
B	Sandy clay, red flecked with white,	4
C	Brown to drab loess,	15
D	Typical loess,	15

The bipartite character of the loess is clearly shown in section 1, and is also shown, though less clearly, in section 5. The

widespread loess sheets of the southern Indiana and Illinois are considered by Leverett to belong to the Iowan age. This would seem to indicate that the lower loess is Illinoian and the upper Iowan.

By reference to Fig. 1 it will be seen that the sections given above approach very close to the extreme southwest corner of the triangular hill land. Gravel was observed to rise 18 feet above the plain in a hill west of section 5. One-half mile west of this point the hills turn northwest in Pigeon Plain. The height of the gravels in the bluffs northeast of Enterprise would indicate that they could be easily found if they existed in this line of hills trending northeast.

A very careful search, in all available places, failed to discover these gravels anywhere along the old river cut-off, and it seems certain that they do not exist there. If this is the case no considerable breach existed in the line of hills from the southwest corner of the triangular upland to Warrick county, at the time of the deposition of the gravel, else it would have been filled with gravel, and at least some fragment of the deposit would be left. This would seem to show the age of the cut-off; it was cut after the deposition of the gravel.

These gravels and sands have been referred to the later Tertiary for several reasons:

First: The composition of the gravel is such that it cannot be referred to the glacial period; no pebbles of undoubted northern origin being found in the beds. It is obvious that, on account of its nearness to the southern limit of the glaciers, no beds of gravels could have been deposited at this place either during or following the ice-invasion without containing glacial pebbles. The main component of the gravel beds is yellow chert, probably derived from the Lower Carboniferous formations, through which the Ohio passes. The fragments of geodes are doubtless mostly from the St. Louis limestone and Upper Knobstone groups of Indiana. The quartz pebbles must have come either from parts of geodes or the Carboniferous conglomerates or both. As the first ice invasion, in this part of the

country, practically marks the beginning of the Pleistocene these gravel beds must be pre-Pleistocene. That the waters would have brought down glacial gravel, had these beds been deposited during any glacial or interglacial period, is shown by

SECTION FROM E. TO F FIG. 1, SHOWING PIGEON PLAIN AND VALLEY OF LITTLE PIGEON
FIG. 12

the fact that in a recent terrace between Rockport and Grandview several deposits of glacial gravel are found.

Second: The gravel and sand is unconformably overlain by loess (*x* Fig. 11.) In several places an old weathered surface is found between the loess and gravel. It seems probable that the lower loess is Illinoian. This is additional evidence pointing to the conclusion that the gravels are preglacial, for as has just been shown they cannot belong to any glacial or interglacial period.

Third: There is a marked lithological resemblance of these deposits to the lower members of the deposits of gravel in the Jackson Purchase Region of Kentucky. The Kentucky gravels were called "stratified drift" by Loughridge in his report on the Jackson Purchase Region,[1] and were referred to the Quaternary. The lower parts of this stratified drift have since been referred to the Lafayette division of the Neocene by McGee,[2] after two conferences of scientists in one of which Loughridge took part. The gravels also agree lithologically with the Lafayette sands and gravels in other parts of Kentucky as described by McGee.

Fourth: The nonoccurrence of preglacial gravels in Pigeon Plain is without a reasonable doubt and their absence and the presence of typical river-bluff loess along the sides of the valley

[1] Kentucky Geol. Sur. 1888, Jackson Purchase Region, p. 57.
[2] U. S. Geol. Sur., 12th Ann. Rep., 1890–1, p. 500.

point strongly to the conclusion that the cut-off was made between the time of deposition of those deposits; there must, therefore, have been a considerable time interval between the deposition of the gravels and the loess during which this valley was formed.

Fifth: Farther up the river[1] gravels are found on both the Indiana and Kentucky sides. Well sections at Rockport show that river alluvium extends over 70 feet below the level of the river plain. These two facts show that after the partial filling of the valley with gravel the land rose and the river trenched through the gravel and deep into the underlying Carboniferous rocks (Fig. 7). This gorge cutting is correlated with the main gorge cutting of the central part of this country caused by the Ozarkian or Post Lafayette uplift. Hence the gravels are pre-Ozarkian and if instead of taking the first glacial invasion to mark the beginning of the Pleistocene the Ozarkian uplift is taken, the gravels and accompanying deposits are still pre-Pleistocene.

There are these five reasons for believing the gravels and sands to be pre-Pleistocene. Briefly they are:

1. Absence of glacial pebbles in the deposit.
2. Unconformity and old soil between the gravel and the loess.
3. Lithological resemblance of beds to known Tertiary beds.
4. Erosion record furnished by old river channel (?).
5. Pre-Ozarkian deposition of gravel.

Since they are pre-Pleistocene they are here referred to the Lafayette divison of the Neocene because, so far as the writer is aware, they resemble no other pre-Pleistocene deposits.

Fig. 2 gives the location of the Lafayette coast line according to McGee.[2] From the Wabash River northward McGee represents the ocean waters as extending in an indefinite way over southern Illinois. Mr. McGee in speaking of this map says

[1] It is regetted that lack of time prevented the examination of the hills below Owensboro, Ky. For several reasons it is believed that a corresponding series of gravel will be found there.

[2] 12th Ann. Rep. U. S. Geol. Sur. 1890, pp, 353-521.

that the data from which it was made was incomplete in the Mississippi embayment and so the coast line is very general.

If these deposits are Lafayette it would seem that an arm of the sea extended up the Ohio valley from the great Mississippi embayment past Posey, Vanderburg, Warrick, Spencer and into, if not past, Perry county, Indiana. In order to fully establish the size and shape of this embayment it would be necessary to examine carefully all lands bordering the Ohio River on both sides from Perry county, Indiana, to the mouth of the Wabash. Figure 2 shows in a general way this supposed extension of the embayment.

The data collected throws some light on the history of the Ohio valley at this point. This history is shown in Figs. 5, 6, 7, and 8. In these no attempt has been made to show the exact character of the rock bottom of the channel as the well sections furnish no evidence on this point. It may be mentioned, as having some bearing on the history, that a rock shelf comes out from the base of the hills north of Enterprise and extends about 20 feet underground to the present river channel. Just across the river wells are reported 60 feet deep and showing that here as at Rockport there is a deep filled valley.

During the pre-Lafayette period the land stood at about its present level, and the Ohio River cut out the valley shown in Fig. 5. This period was followed by the Lafayette submergence when the sands and gravels were laid down as an estuarine deposit and the valley probably assumed about the appearance shown in Fig. 6.

During the post-Lafayette or Ozarkian period the land stood more than 70 feet higher than now and the river after cutting through the Lafayette sands and gravels cut deep into the underlying Carboniferous rocks (Fig. 7); cutting from side to side it took away the Lafayette gravels in places along the side of the river leaving deposits only here and there. Then followed another subsidence and the river filled up its channel making a broad alluvial flood plain. At some time after the post-Lafayette high level the loess was deposited on the bluffs on either side

making them 15 to 30 feet higher. This gives the valley of the present (Fig. 9).

Figure 9 is a diagrammatic representation of these earth oscillations of the Ohio valley during the Lafayette part of the Neocene and the Pleistocene, the Columbia submergence being based on the supposed aqueous origin of the loess of this region. Only the vertical movement is here represented as no data bearing upon the time covered in each movement was collected.

It should be noticed that this record of continental oscillation agrees very closely with the record of the Mississippi embayment, as given by McGee.[1]

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[1] U. S. Geol. Sur., 12th Ann. Rep., 1890, p. 429.

THE BROWN OR YELLOW LOAM OF NORTH MISSISSIPPI, AND ITS RELATION TO THE NORTHERN DRIFT.[1]

OUTLINE.

I. General characteristics of the Brown or Yellow Loam.

II. Its stratigraphic relations and its distribution in north Mississippi.

A. Its relations to the Lafayette.

Unconformity between the Brown Loam and the Lafayette proper indicated by:

(1) The fact that wherever the Lafayette occurs in force, covered by the loam, the greater part of the present surface relief is due to the irregular contours of the Lafayette, rather than to varying thickness of the former, resulting from recent erosion: topographic relief of the Lafayette greater than that of the Brown Loam.

(2) (*a*) The feathering out of the Lafayette, and its alternate disappearance and reappearance eastward and northeast from Oxford, Miss., thus leaving erosion remnants intercalated between the Brown Loam and pre-Lafayette formations.

(*b*) The presence in the surface formation of northeast Mississippi, where, in many places, the Lafayette is now absent, of materials similar to those of the Lafayette where typically developed.

(3) The degree of oxidation produced in the Lafayette prior to the deposition of the Brown Loam.

(4) The occasional presence of thin patches of a seemingly distinct formation intercalated between the two, composed of materials similar to those of the Lafayette, but unconformable alike with the Lafayette below and with the Brown Loam above, thus indicating, probably, *two erosion intervals* of greater or less duration between the time of the deposition of the Lafayette and that of the Brown Loam.

(5) The character of fossil plants found in bowlders of clay in this intermediate formation, near Oxford, Miss., and derived presumably from the Lafayette.

Summary: The preglacial age of the Lafayette.

B. Its relation to the Loess (or Bluff formation of Hilgard).

III. Origin and age of the Loess Loam.

A. Lower limit of the formation in north Mississippi.

B. Upper limit in the same region.

C. Conditions under which the formation was deposited.

D. Subsequent alteration.

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[1] This paper is based upon a series of personal observations extending continuously from Riverton, Alabama, to Memphis, Tennessee, in a crescentic curve passing

I. GENERAL CHARACTERISTICS OF THE BROWN OR YELLOW LOAM.

The predominant material of the formation in this section to which Hilgard has applied the name of brown loam, or yellow loam is as he states (*Agriculture and Geology of Mississippi*, p. 198), "that of a mellow clay or loam, without any definite structure or cleavage, variously tinged with iron; containing from 10 to 25 per cent., usually, of siliceous sand, the rest being clay mixed with finely divided silica, and forming, therefore, rather loose, mellow soils, and good brick clays.

The loam proper of this formation varies from the brownish-black color of our richest upland soils, where the coloration is due largely to the presence of organic matter through yellow and red, to the grayish-white "buckshot," or "crawfish," lands, which are ill suited to agricultural purposes.

In view of the immense value of these "buckshot" (which characterize the lands of that name by their presence in large number) to the geologist in enabling him to identify with reasonable certainty loams of this period occurring in this region, a brief description of them will not be out of place. They are not confined to the so-called "buckshot" or "crawfish" lands, but

through the counties of Tishomingo, Prentiss, Union, Lee, Pontotoc, Lafayette, Yalobusha, Panola, Tate, Marshall, and De Soto in Mississippi, and Shelby county, Tennessee.

In its preparation invaluable aid has been received from the writings of Hilgard, McGee, Chamberlin, and Salisbury. To my former instructors in field geology, Messrs. A. P. Brigham, H. B. Kümmel, and T. C. Chamberlin, credit is due for valuable training in field methods; to Professors Chamberlin and Salisbury I am also indebted not only for instruction in the theoretical aspects of the science, but for suggestions as well, given both in and out of the class room, bearing upon the subject under discussion; and to Professor Chamberlin I am under special obligations for a critical review of the first draft of this article.

Thanks are also due to Mr. Charles Strong, M.A., former Fellow in Chemistry, University of Mississippi, for a chemical analysis of "buckshot" from the yellow loam; to Dr. F. H. Knowlton, for the identification of fossil plants herein described, and to various others for kindnesses shown me.

But for the collection and collation of data on which this paper is based, and for the conclusions derived therefrom, I alone am responsible. The accompanying photographs were taken by Sanders and Sweeney, Oxford, Mississippi.

are liable to be found, in smaller numbers, wherever the Brown Loam occurs, and one will rarely travel far in the loam region without finding them. They seem to be entirely characteristic of the Brown Loam in this vicinity, not being found in any of the older formations on which it directly rests—that is, as far as my observation extends—and over most of the territory the loam is itself the surface formation. It is true that along streams frequently "second bottoms" are to be found (sometimes as "buckshot" lands), and the more recent alluvial deposits, the latter, however, never containing concretions: but the former are undoubtedly, in many cases, merely terraces of degradation cut in the Brown Loam, when, because of increased velocity due to increase of slope or to decrease of burden, or to both, the streams began to erode the bottoms of their channels more rapidly than their sides, and so ceased to overflow only within the past twenty-five or thirty years.

But it is not always an easy matter in the field to separate the loam from more recent formations. This subject will be more fully treated under the head "Upper Limit in the same Region."

These "buckshot" are usually more or less rounded, yellowish-brown on the oxidized surface, black in the interior, possessing no definite structure, and ranging in size from that of a small shot to that of a small marble. Not infrequently, however, they are much larger, when they usually tend to become more flattened and angular, and are frequently found cemented by iron oxide into a rather friable conglomerate.

These ferruginous concretions have undoubtedly been formed by segregation from the mass of the loam, as have somewhat similar ferruginous concretions and the calcareous nodules from the loess, and especially the friable conglomerate already mentioned, has evidently been cemented *in situ*. (Compare paragraph 338, p. 199, *Agriculture and Geology of Mississippi*.) Typical specimens of the "buckshot" from the loam of Tate county, ground up together and analyzed at my request by Mr. Charles Strong afforded:

	Per cent.
Silica (SiO_2),	78.55
Ferric oxide (Fe_2O_3),	14.88
Water,	1.51
Sulphuric acid (H_2SO_4),	1.03
Lime (CaO),	1.944
Alumina (Al_2O_3),	2.06
Total,	99.974

Perhaps the most notable characteristic of the brown loam is its general disintegrated, "rotten" appearance, with the entire absence of anything simulating stratification in the loam proper, notwithstanding the fact that the particles composing it are usually fine and such as ought, it seems, to have been neatly stratified if deposited under ordinary conditions, and not subjected to subsequent atmospheric and aqueous action. This subject will be more fully discussed under the general head, "Origin and Age of the Loess-Loam."

II. STRATIGRAPHIC RELATIONS AND DISTRIBUTION OF THE BROWN LOAM OF NORTH MISSISSIPPI.

According to Hilgard (*Agriculture and Geology of Mississippi*, pp. 197–198), "the yellow, brown, or reddish loams which have been repeatedly mentioned as forming the surface, and therefore essentially, the soils of the greater portions of the State of Mississippi constitute to all appearance an independent aqueous deposit, posterior to the Orange Sand (Lafayette) and the Bluff formation, and anterior to the alluvial formations of the present epoch. The great thickness which this loam stratum attains in some regions, its distinct definition as well as its comparative independence as to its character of the formations immediately underlying, preclude its being claimed as a mere surface disintegration of the older formations. The nature of its materials and the entire absence of stratification lines distinguish it sufficiently from the Orange Sand where it immediately overlies the latter; while the absence of any large amount of lime, except where it is in immediate contact with strongly calcareous formations, the

presence of a considerable amount of hydrated peroxide of iron as well as the want of proper fossils as distinctly separate it from the Bluff formation of the Mississippi River. . . . .

"From the appearance of the loam stratum, even on high ridges and elevated uplands, it is obvious that its deposition took place, in part at least, anterior to the great denudations which have produced the present surface configuration; nevertheless, its increasing thickness as we approach the immediate valley of the Mississippi shows, as in the case of the Bluff formation, that this great channel was already in existence.

"On the Tombigbee, and on the lower Tallahatchie, Yalobusha, and Big Black, a similar increase in the thickness of the loam stratum may be observed. But on the smaller water courses this is the case only to a very limited extent, showing that, although at the time of the deposition of the loam the channels were already more or less impressed upon the surface and high ridges existed which remained above the level of the water which deposited the loam, the minor denudations which have caused the present undulating surface had as yet exerted but little influence. The lines of contact between the Orange Sand and Loam, where the latter is evidently *in situ*, are generally much less undulating than are those between the Orange Sand and the older formations."

A. *Relation of the Brown Loam to the Lafayette.*—From the foregoing account, it would appear that the Brown or Yellow Loam proper is a formation *sui generis*, deposited on a previously eroded land surface in such wise as not to turn aside the larger preëxistent streams, and distinguished from the Lafayette only by "the nature of its materials, and the entire absence of stratification lines where it immediately overlies the latter." These criteria for the discrimination of the Brown Loam and the Lafayette will, of course, fail of application (1) where there is no great difference in the nature of the materials of the two formations, as is frequently the case, especially near their line of contact, and (2) where the upper part of the Lafayette, as well as the Brown Loam, is unstratified.

Wherever the loam attains a thickness of 10 or 12 feet—and it is rarely thinner than this for any considerable distance—it is usually not difficult to identify it, especially its upper portion, but, as Hilgard has long ago pointed out, this formation is frequently so modified by underlying terranes as to render its delimitation in those places a matter of great difficulty, if not impossible. For instance, locally the characteristic loam may be replaced by sand variously colored; and when all traces of stratification, if they ever existed, have become obliterated through the action of percolating chalybeate waters, which both color and cement the sand grains, and when this red, sandy phase of the "Brown Loam" or "Yellow Loam" rests directly upon similar sands of the Lafayette—whence the former have generally been derived—it frequently becomes a matter of impossibility to draw any certain line between the two. This is often the case in the "red lands" of the Pontotoc Ridge and its northward continuation, the "Buncombe Hills." However, judging from an exposure near the depot in the town of Pontotoc, and from numerous other sections on the ridge, both the brown loam and the Lafayette seem to be represented in the Pontotoc Ridge; but as we shall presently see, the Lafayette is frequently absent in northeast Mississippi, the Brown Loam resting directly upon still older formations.

A section in the cut on the Illinois Central Railroad just south of the depot at Oxford shows typical loam at the top, grading into rotten or friable clay, which, becoming more sandy below, passes insensibly into a semi-indurate, massive red sandstone. The base of the section here shows nicely stratified sands and clays, presumably of Lafayette age, though possibly later, but no definite line can be drawn between the two formations at this exact point.

While we cannot always with certainty determine, in the field, the limits of the two formations, and while there are to be found places of seeming local conformity, which we should naturally expect, still the two can generally be separated without difficulty, because, when typically developed, the two forma-

tions possess little in common. And from such good exposures I have obtained strong evidence of great and widespread unconformity between the Brown Loam and all older formations. A great erosion interval is indicated by the following facts:

1. A considerable interval of erosion between the Lafayette and the Brown Loam periods is indicated by the fact that wherever the two occur in force the greater part of the present surface relief is due to the irregular contours of the Lafayette rather than to varying thickness of the post-Lafayette resulting from recent erosion. In other words, the topographic relief is greater in the Lafayette than in the post-Lafayette. This is indicated by the greater thickness of the post-Lafayette in existing valleys than on hilltops, even where there has been no recent deposition in the former of loam washed in from the hills. Many Lafayette hilltops, frequently capped with ferruginous sandstone bowlders, seem to have been above water continuously since Lafayette times. It seems that the land in this region has not been under water long enough since the period of Lafayette erosion to allow the complete filling in of the channels cut in the Lafayette; and this is partly due to the fact that deposition was taking place simultaneously, though not to so great an extent, over the greater part of the hills and ridges into which the Lafayette had been cut. And so the most of our present streams, especially the larger ones, are of the superimposed type—superimposed by sedimentation.

The greater deposit of sediment in the valleys is probably due to the fact that the valleys were submerged for a longer time, but partly also to the greater effect of their deeper waters in the checking of currents and consequent precipitation of sediments.

2. Another line of evidence of unconformity between the Lafayette and the Brown Loam, closely related to the one just given, lies in the fact that the Lafayette frequently feathers out, leaving the Brown Loam to rest directly upon the formations older than the Lafayette. Sometimes the evidence of the former extension of the Lafayette over the area in question is not con-

clusive, as where the Brown Loam rests directly upon the pre-Lafayette formations, and there is no trace of the Lafayette left in the vicinity, it is impracticable under such circumstances to say whether the Lafayette once covered the given locality and has been entirely removed by erosion, or whether it was never present. Such a state of things is exhibited in many places in the country near New Albany, Miss., and elsewhere. The Brown Loam mantles the hills and dales of this region, resting in many places directly upon the Cretaceous, sometimes upon the Lafayette, as it does elsewhere (as we shall presently see) upon the Lignitic Tertiary, and as it does regularly upon the Lafayette further westward. It cannot be a surface disintegration of the Cretaceous at this place; but it is seen to be directly continuous with the loam stratum elsewhere observed, and was without doubt formed at the same time and in the same way. (As to the geological relations of the surface soil, Brown Loam, in this region, see also *Ag. & Geol. of Miss.*, paragraphs 335, 336, and 337, pp. 198–199.)

But sometimes the Brown Loam rests upon older formations once covered by the Lafayette, which has subsequently been removed by erosion. There are two lines of evidence: (*a*) Near Oxford, Miss., where the Lafayette is typically developed, it attains a maximum thickness of something like 200 feet. But towards the east it soon thins out, exposures of the Lignitic being quite common within eight or ten miles of Oxford.

As the region of Flatwoods is approached, the Lafayette becomes discontinuous, and patches of it only are to be found intercalated between the Brown Loam and the Northern Lignitic. The Lafayette seems to give out altogether several miles before the Flatwoods are reached. At the exact western limit of the Flatwoods, some ten miles west of Pontotoc, on the Pontotoc and Lafayette Springs road, several feet of typical brown loam are seen to rest directly upon the blue clays of the Lignitic. Over the Flatwoods region, here six or seven miles wide, both the Brown Loam and the Lafayette are usually absent, the latter always, the former occurring in limited patches towards its east-

ern border. Both formations seem to be found again in the Pontotoc Ridge and Buncombe Hills, as already noted; but the Lafayette soon gives out and seems not to appear again, at least not strongly and typically developed. For example, over the greater part of Union, Prentiss, and Tishomingo counties, the Brown Loam rests upon formations older than the Lafayette. Frequently the Brown Loam has been removed by erosion, and the "Rotten" Limestone, Selma, or Tombigbee Chalk comes to the surface. Exposures of this latter formation are quite common in the prairie region, as is well shown around Booneville, Baldwyn, Marietta Springs, etc.

On a hilltop about fourteen miles from Booneville and sixteen miles from Iuka, on the old Booneville and Iuka road, several feet of Yellow Loam repose directly upon stratified, blue, pyritiferous clay of the Eutaw (?) group.

At Bay Springs, in southwest Tishomingo county, the Brown Loam rests either directly upon Sub-Carboniferous sandstone or there is a thin intervening stratum of pyritiferous Eutaw (?) clay—the source of the chalybeate waters of the springs. (*b*) While there is plenty of orange-colored sand in east Prentiss and in west Tishomingo counties, nowhere in this region did we find materials of undoubted Lafayette age *in situ*, though it seems likely that the Lafayette once covered this area, and that small patches of erosion remnants may still exist, because materials similar to those found in the Lafayette further west are here found to a greater or less extent scattered irregularly through the Brown Loam. The quartzose pebbles of Tishomingo county, for example, described by Hilgard (*Ag. & Geol. of Miss.*, 1860), and referred to the Lafayette epoch, seem to occupy an entirely different stratigraphic position from the majority of those in the western region, *i. e.*, from Memphis, Tenn., to Grenada, Miss., and southward, which are evidently of Lafayette age. In the former region these pebbles are found intermingled with the Brown Loam, as shown in many places near Iuka and elsewhere, while in the latter region they are invariably below the Brown Loam, sometimes in apparent local con-

formity with its base, elsewhere well within the Lafayette The gravels of this western belt were all evidently first transported to this region and deposited during the Lafayette epoch, and towards its close, though in many places they have been subsequently moved locally and redeposited at the base of the brown loam. On the principle of homogeny, the gravels of the eastern belt are thought to have been brought down originally at the same time with, and in the same manner, as those of the western region; but owing to the complete, or almost complete, removal by erosion of the Lafayette in the eastern region, these gravels have been shifted from their original positions and redeposited within the Brown Loam, and by the same waters (for I hold the Brown Loam to be essentially an aqueous deposit) which deposited the finer materials of the brown loam. These waters need not have been swift in order to transport pebbles, for these were probably only locally shifted and let down from higher to lower levels. On the other hand, the fineness of the materials of the bulk of this formation gives evidence that the formation, as a whole, was deposited by sluggish currents overloaded with fine sediment.

And so an application of the principles of homogeny, as defined by McGee (*12th Ann. Rep. U. S. Geol. Surv.*, p. 381 *et seq.*) to the Brown Loam of the whole of north Mississippi, together with the fact that undoubted erosion remnants of the Lafayette are to be found as far east as the Pontotoc Ridge, would seem to demand the former extension of the Lafayette over the whole of the area in question. A comparison of the hypsographic distribution of existing patches of the Lafayette with the hydrography of the region strengthens this conclusion, since remnants of the Lafayette are to be found on the highest hills, while on lower lands near by, the Lafayette may be entirely absent. As to the original thickness of the Lafayette, we have no way of determining this; but the evidence, direct and indirect, just presented, indicates a considerable erosion interval between the Lafayette and the Brown Loam during which a large part of the former had been removed prior to the deposition of the latter.

3. The degree of oxidation and attendant phenomena produced in the Lafayette prior to the deposition of the Yellow Loam, by atmospheric and aqueous agencies, likewise tell the story of a considerable interval of chemical as well as mechanical erosion between the periods represented by these two formations. (See *Am. Jour. Sci.*, Vol. XLI, p. 370.)

4. The facts already presented show conclusively that a long period of erosion intervened between the time of deposition of the Lafayette and that of the Yellow Loam. Over most of the area embraced within the scope of this paper the Lafayette seems to be essentially a continuous deposit, with the Yellow Loam resting directly and unconformably upon it, although its irregular stratification and the alternating layers of coarser and finer material indicate varying local conditions such as would result if the formation were deposited in the manner supposed by Hilgard.

McGee finds evidence in some localities of a twofold and even of a threefold division of the Lafayette, the divisions being separated by "pseudo-unconformities," which, according to him, represent only local shifting of currents, and consequent change in deposition, and do not mark the limits of distinct episodes. (*12th Ann. Rep. U. S. Geol. Surv.*, pp. 453–456, and elsewhere.)

But sections observed by the writer have caused him to doubt the unity of the Lafayette, as now defined in its type locality, and to raise the question whether the uppermost member of the Lafayette may not represent a distinct formation.

Occasionally there is found a stratum of clay and sand, or of clay alone, intercalated between the main bulk of the Lafayette and the Yellow Loam, and sharply separated from both by irregular or billowy erosion lines. This deposit is usually only a few feet in thickness, and consists, (*a*) of compactly bedded pipe clay, (*b*) of interlaminated clay and sand (the different layers sometimes quite thin, sometimes several inches thick), or (*c*) of a heterogeneous, unsorted mixture of sand and clay bowlders of various shapes and dimensions, resembling very much in physical characteristics, the unsorted till of the North.

An excellent illustration of the first is found in an exposure of some thirty or thirty-five feet, four and one-half miles south of Chulahoma, Marshall county, Mississippi. Here we find several feet of compactly bedded pipe clay, with a billowy upper surface, covered by eight or ten feet of Yellow Loam—from which it is quite sharply separated—and resting upon a decidedly eroded surface of cross laminated Lafayette sand. The three formations are distinctly traceable for perhaps a hundred yards, when the surface of the Lafayette descends so far as to be no longer exposed. Stratigraphically and lithologically the three formations are here very distinct, and show no evidence whatever of grading into one another. The erosion line between the clay and the sand is as sharply defined as that between the clay and the Yellow Loam. This clay, moreover, gives evidence, in its irregular streakings of ferric oxide, of having once been highly fossiliferous, and this evidence is strengthened by the fact that it still contains a few leaves in a fine state of preservation. These fossils were evidently formed *in situ* and not plucked from older formations and redeposited. Not enough were found to be of any practical value in determining the geological age of the clay stratum in which they occur, and those found have not been identified. Of the specimens in my collection at least two distinct species are represented, the one having a very small netted veined, linear-oblong leaf, resembling a willow leaf, or the leaf of a water oak, the other also netted veined, oblong-ovate, and entire, but much larger than the first, being about an inch broad by two and a half inches in length. If the formation in question belongs to the Lafayette, then the Lafayette here contains fossils of its own in its upper part; but it appears to belong to a distinct epoch or episode, and the presence of fossils in clay would seem to indicate conditions of deposition different from those which appear to have obtained when the Lafayette sand, directly underneath, was being deposited.

The accompanying photographs represent a continuous section one-third of a mile north of the depot at Oxford, Mississippi. A cut in the Illinois Central Railroad at this place, giv-

ing an exposure of thirty to thirty-five feet, shows a section very similar to the one just described, except that the middle member here consists of eight to twelve feet of clay bowlders, large and small, rounded and angular, mixed indiscriminately with sand. This section shows:

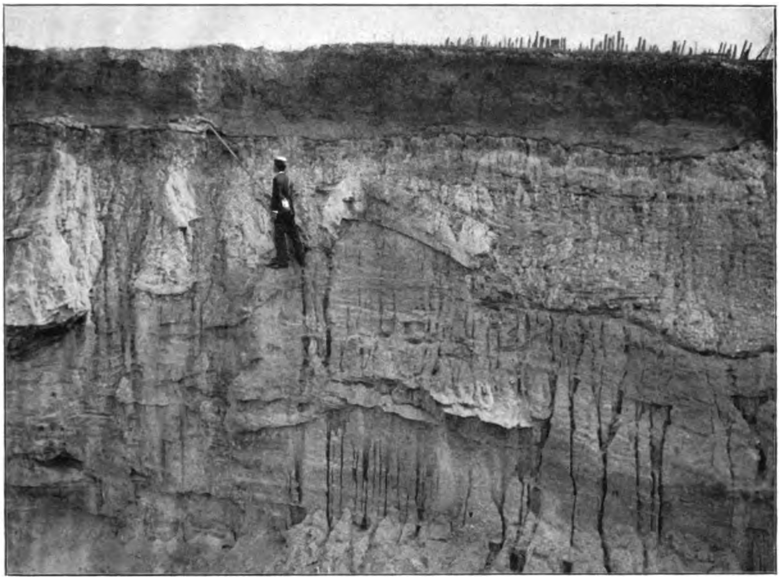

FIG. 1.—Section near the depot at Oxford, Mississippi, showing two members of the Columbia Formation and their relation to the Lafayette. (*a*) Yellow Loam; (*b*) fossiliferous clay bowlders and sand; (*c*) cross-laminated Lafayette Sand.

(*a*) At top, 0–8 feet of Yellow Loam.

(*b*) 8–12 feet of clay bowlders and sand.

(*c*) At base, 0–12 feet of cross stratified Lafayette sand.

Here the three formations are very distinct lithologically, and there is no evidence of the gradation of one into another either in a lateral or in a vertical direction.

The top stratum (*a*) is a typical loam, while (*b*) consists of sand mixed with clay bowlders, rounded and angular, varying in size from mere pellets up to slabs one to two feet thick, four to six feet long, and of unknown width, but presumably of not

more than a few feet. The lowest stratum (*c*) has been sufficiently described above.

This bowlder stratum (*b*) consists of rock materials similar to those of the directly underlying or adjacent Lafayette; so from a lithological standpoint two views of the origin of this stratum are possible. Either it and (*c*) have been derived from the same pre-Lafayette formation, or formations, and the apparent unconformity between them is to be regarded as a "pseudo-unconformity," as explained by McGee, or the two are distinct formations, and the upper one has been derived from the lower.

The latter I regard as the more probable for the following reasons:

1. The extent to which the underlying sands have been eroded, and the very abrupt change from cross laminated sands (seemingly a local delta deposit) underneath, to a bowlder stratum of the character described—these seem to indicate extraordinary conditions of deposition for the bowlder stratum, and an amount of erosion of the underlying formation, which could not be accounted for by a mere local shifting of currents, with no appreciable changes of level nor consequent interval of erosion.

Smaller clay pellets, it is true, occur quite frequently elsewhere, in the body of the Lafayette, but never so large, as far as I am aware, as those just described.

2. The size of many of these bowlders, and their frequent angularity (which may be due in part, however, to subsequent atmospheric action), as well as their composition and physical texture, render it highly improbable that they have been transported by running water for any considerable distance.

The Lafayette proper is about 150 to 180 feet thick in this vicinity, as shown by recent well borings; and the Lignitic, the immediately underlying deposit, comes to the surface only at a distance of several miles to the eastward. A well recently bored upon the university campus, after passing through a few feet of surface loam penetrated the Lafayette formation, and

FIG. 2.—Northward continuation of Fig. 1. (*a*) here removed from center of photograph by erosion. Talus at base composed largely of fossiliferous clay bowlders from (*b*).

reached the Lignitic beds at a depth of about 180 feet. Wells in Oxford struck the same beds at depths of 155 to 160 feet.

The pipe clay of which these bowlders are composed is also of an unctuous, kaolinic nature, such as would not seem able to suffer prolonged transportation by running water without disintegration.

3. The clays of this bowlder stratum are altogether unlike those of the Lignitic beds near here, which are generally blue, or black, pyritiferous, and friable when dry. But the clays, also, of the Lafayette proper, which must have come from a distance, show a like dissimilarity to the Lignitic clays, having become altered probably in color and relieved largely of carbonaceous matter and of iron pyrites (if they came from the Lignitic) during transportation or subsequent to their redeposition. So the argument based on the dissimilarity of the clay bowlders to clays of pre-Lafayette age in this vicinity is of no value considered apart from the conditions under which they must have been deposited, and the short distance to which they could have been transported by running water.

4. These bowlders are frequently highly fossiliferous, containing plant specimens preserved in ferric oxide, and prolonged water transportation, if possible, would probably have defossilized them by the removal of the iron oxide in solution. The fact that no well-defined fossils peculiar to itself have yet been found in the Lafayette might be adduced as evidence that these fossiliferous bowlders must have come from some other source (and the character of the fossils as described by Dr. Knowlton would seem possibly to indicate their derivation from an earlier formation); but this does not necessarily follow, since plants must have existed during the Lafayette, and if none have been found in it the explanation is probably to be found in the fact that its materials, as a rule, are not well adapted to the preservation of organic remains. Its clays, moreover, as already pointed out, are very similar to those of the stratum under discussion, and the latter are very rarely fossiliferous. It is only occasionally that we find fossils in compact, close-textured, impermeable and

highly colored clays. Where there has been freer circulation of water, and where roots of recent plants have penetrated them, these clays have become more friable and partially decolorized, the change from their former condition being indicated, as already noted, by the peculiar distribution of the remaining ferric oxide, which frequently retains the shape of stems and leaves but not their texture. And in many instances such markings are traceable by the lighter color and by the more disintegrated condition of the clay where fossils seem to have existed, the ferric oxide having been, it seems, more completely removed, subsequently, than from the surrounding clay. Much care, however, is needed in the interpretation of many of these tracings, part of which are due to the action of roots of recent plants, part to the collection of ferric oxide on slickenside surfaces resulting from the jointing of the clay and the scratching of joint surfaces by their movement over sand grains. Such markings frequently give a fluted appearance resembling very much the impressions of parallel veined leaves.

The foregoing considerations, it seems to me, render it highly improbable that the coarser and clayey materials of this peculiar bowlder conglomerate could have been transported for the distance of several miles by running water.

The peculiar admixture of sand with clay bowlders, large and small, rounded and angular, with no trace of sorting, suggests to the writer the possibility of this deposit having been formed after a partial reëlevation succeeding the Lafayette subsidence, by the sapping of the banks of a small post-Lafayette lake or stream.

The inability to discover similar plant remains in the adjacent Lafayette might be explained by the removal of the original beds by plantation.

It is barely possible that this particular deposit may have been made by floating ice during the first interglacial epoch (or more probably during the first interglacial episode of the first glacial epoch), and I shall present, later, evidence of iceberg action at this time, in this vicinity—but the elevation of

this deposit above the larger water courses, such as the Tallahatchie and Yocona rivers, between which it lies and down whose swifter waters most of the icebergs probably traveled, renders it hardly probable that the deposit was formed in this way.

According to Professor Chamberlin the Natchez formation occupies similar relations to the Lafayette and to the Loess of the northern Mississippi, though it contains crystalline pebbles in addition to materials derived from the Lafayette; and he suggests that both may have been formed at the same time, the two representing a distinct episode, or epoch, between the Lafayette and yellow loam.

On this hypothesis there was a period of upheaval succeeding the Lafayette deposition, during which all formations then existing were greatly eroded. This was followed by subsidence in the region of the lower Mississippi, accompanied by the deposition of the Natchez formation and of the stratum between the Lafayette proper and the Yellow Loam in this vicinity. Then followed an interval of upheaval and erosion, marked by the irregular contours of the upper surface of the bowlder stratum of the Oxford section and by the presence of an old soil at the summit of the Natchez formation. It is not to be understood, however, that the supposed Natchez subsidence was great enough to submerge the areas in question below sea level, for the deposits have not the characteristics and distribution which would probably have resulted from the action of ocean waves.

The deposits were probably formed when the land surface was at a comparative base level, and are of fluvial and lacustrine origin, and not marine, nor even estuarine. The amount of geological time represented by this hypothetical oscillation (during which the Natchez formation and its supposed congener in this vicinity were deposited and subsequently eroded prior to the deposition of the Loess and the Brown Loam) is probably very short, though it serves to emphasize the time interval between the Lafayette and the Brown Loam.

5. Other evidence bearing on the age of the Lafayette, and

therefore upon that of the Yellow Loam, is that furnished by the character of fossil plants found in the bowlder bed at Oxford previously described. The value of this evidence, however, is diminished by the fact that it is not absolutely certain that they came from the Lafayette formation. These fossils are mainly leaves and small stems, and occasionally an acorn (?), of what "seems to be a new and very fine species of Quercus" (Knowlton); and sometimes there is found a specimen of a palm, that "is with little doubt Flabellaria Florissanti, Lx, found originally in the Eocene of Colorado" (Knowlton). The preserving agent is apparently red hematite which shows up the smallest veinlets of the leaves. Indistinct traces of grass-like plants are also to be found. In answer to inquiries as to the probable age of these fossils, as referred to the accepted geological time scale, and the probable climatic conditions then prevailing, as indicated by the nature of the plants, Dr. Knowlton has this to say: "The data upon which to base an opinion of age is, as you see, quite too scant for a positive assertion. I should say, however, that it indicated rather an Eo-Lignitic than later age. Could it be possible that the clay in which the plants occur was a pocket or lens which had been torn from the Eo-Lignitic and redeposited in the Lafayette? However, I incline to the opinion that they are Eocene rather than later, but more material will be needed to confirm or disprove this . . . . the above mentioned plants do not indicate any marked change from the climate of the present day . . . . I imagine that when the fossil flora is thoroughly studied we shall find that species or forms have persisted for long periods of time with comparatively little change."

This paper deals with the study of the Lafayette formation only to the extent necessary for fixing the lower limit of the Yellow Loam. And the foregoing evidence of unconformity between the two is adduced in corroboration of the evidence presented by Chamberlin and Salisbury (*Am. Jour. Sci.* Vol. XLI, p. 359 *et seq.*) in favor of the preglacial age of the Lafayette. The proof of the glacial age of the Loess of the Missis-

sippi valley, presented by them in the article just referred to, appears conclusive.

I have shown that the Yellow Loam occupies the same position with reference to the Lafayette in the interior, that the Loess does along the Mississippi valley. By the foregoing considerations, and by a review of the relation of the Yellow Loam to this loess in this vicinity, I hope to strengthen the evidence already presented by McGee that the Yellow Loam and the Loess are not only homotoxial but that they are also genetically related.

B. *The relation of the Brown or Yellow Loam to the Loess* (*or Bluff formation of Hilgard*).—These two deposits were discriminated by Hilgard, who considered them as separate formations, the Brown Loam being the younger (*Ag. & Geol. of Miss.* 1860).

Later, McGee and others have noted the somewhat complex relations of the two along the bluffs of the southern Mississippi, especially around Vicksburg and Natchez (*12th Ann. Rept. U. S. Geol. Surv.*, p. 392 *et seq.*).

The present paper has nothing to do, except in a very general way, with this area, concerning which McGee says: "The loess of the lower Mississippi region may be characterized as a peculiar condition of the Brown Loam, or as an imperfectly demarked phase of the great formation into which both deposits fall." Having reached the same conclusion from a study of the area embraced within the scope of this paper I shall now proceed to state the grounds on which this opinion is based:

1. The Drift of the North is the surface formation, to which the loess of the river valleys bears an ascertained and definite relation, as already noted. During the Glacial period there were extensive continental oscillations during which, according to some authorities, the whole southern part of our continent was submerged: so, on *a priori* grounds, we should find as the "southern equivalent of the northern Drift" a mass of water-deposited sediment more commensurate in quantity with the Drift than is the Loess alone. Evidence of such submergence will be brought out in the further discussion of this subject.

2. Having traced the surface formations from Bear Creek, on the Alabama-Mississippi-Tennessee lines, to the Mississippi River at Memphis, and to the "bluffs," 40–50 miles below, I found the loess and the loam to be absolutely continuous, the former usually being absent, or not characteristically developed, except within a few miles at most of the existing "bluffs" and frequently in the "bluffs" themselves replaced entirely, locally, by loam, with characteristic ferruginous "buckshot," to the very base.

The following characteristic sections will serve for illustrations:

A. *Sections at Memphis, Tenn.*—(*a*) Bluff just north of Custom House; at base, typical bluff-colored loess, non-effervescent throughout its mass, but containing characteristic concretions, calcareous and ferruginous, — the latter tubular or cylindrical rather than rounded — and obscure fossils. This passes laterally into yellow or brown loam, and also becomes loamy at the top — as the loess quite frequently does. Evidently the loam here is only modified loess, or the latter is only a peculiar phase of the loam. This is the most characteristic exposure of the loess observed at Memphis. Going down the river both fossils and concretions (of the loess proper) become less frequent. (*b*) Section about one-half mile north of the river bridge; 60–70 feet (estimated) of typical brown loam with its characteristic "buckshot" to the very water's edge, where it rests unconformably on the Lafayette — the loess being entirely absent. Exposures near here show a loess-like loam devoid of fossils and concretions. (*c*) Section about one-third mile north of river bridge. (1) At top 60–70 feet of loam. (2) White and reddish sand, cross laminated, and containing occasional pebbles, sometimes stratified, 10 feet. (3) Stratified Lafayette gravel, 2–3 feet exposed. The lowest 5 or 6 feet of (1) are pronouncedly sandy, the upper part of (2) humus stained, indicating an old soil. (*d*) Section about 30 yards south of the last. Here we have about 60 feet of yellow loam, with "buckshot" at its very base, resting directly upon stratified

Lafayette gravel, No. (2) of the preceding section being absent.

B. *The relations of the Loess and the Brown Loam along the "bluffs" of southwest Tate and northwest Panola counties.*— In this region the bluff is much higher, though far less precipitous than at Memphis, where it is being continuously washed at its base. The estimated height of the rampart at Askew's Bluff, northwest Panola, is 200 feet. But thence it diminishes in altitude both northward and southward. Concretions and fossils are generally to be found in abundance within a few hundred yards eastward from the present base of the rampart in this region, but no clear cut section showed in any one place the characteristics and the relations of the Loess from the top down to the Lafayette. However, a continuous, descending section from the summit of Askew's Bluff passes over several feet of gravels, similar to those at Memphis and southward, about two-thirds of the way down. Further down, the blue clays of the Lignitic are struck and something like 40 or 50 feet are exposed; and one-quarter mile north, in a ravine, there is found a seam of cheesy lignite one or two feet thick. Traced eastward from this point the loess passes insensibly into the surface loam. The main body of the Loess here, as elsewhere, is as a rule, less disintegrated than the Yellow Loam; but the formation is apt to be more loam-like at the top, where most exposed to atmospheric action.

Traced northward the Loess seems to maintain its typical character as far as studied, *i. e.*, to the road running west from Senatobia. Proceeding eastward along this road from the bluff, here quite low, the shells soon disappear from the Loess, but limestone concretions were found as far as four or five miles from the foot of the bluff, at a point one mile east of Strayhorn. Between these two places the Loess frequently alternates with loam, and at one place, about one and one-half miles west of Strayhorn, limestone concretions and ferruginous "buckshot" were found associated together in a sort of loess-loam, which became more loamy at the top. Here, as frequently, the limestone concretions assume dendritic forms, caused evidently by

percolating calcareous waters in ramifying crevices. Specimens were taken from such crevices.

No microscopic examination of the loam was made for comparison of its mineralogical constituents with those of the loess; but owing to a greater degree of subsequent alteration in the former it seems doubtful whether such tests when made would prove entirely satisfactory. The chemical composition of the two, in their typical development, seems to differ rather in degree than in kind, from the same cause, and the two pass into each other by insensible gradations.

From the foregoing it would appear that, if my observations be accurate, the Brown Loam and the Loess of this region are not only homotaxial but synchronous as well.

III. ORIGIN AND AGE OF THE LOESS LOAM.

The Loess of the north has been distinguished as belonging to two separate epochs, and a similar twofold division of the same in the south is mentioned as a probability by Chamberlin and Salisbury, in an article entitled "On the Relationship of Pleistocene to the pre-Pleistocene formations of the Mississippi Basin, south of the limit of glaciation" (*Am. Jour. Sci.*, Vol. XLI). The Yellow Loam is here considered as the interfluvial equivalent of the Loess, but the writer has seen nothing to suggest, or which would justify, the division of the former into two or more parts, separated by a time interval of greater or less duration. On the other hand, sedimentation generally seems to have been continuous from the beginning to the close of the period —the first deposits, frequently composed mainly of local and coarser materials, being directly followed by the finer deposits which constitute the main bulk of the formation. It does not follow that the Yellow Loam formation may not be of a bipartite nature elsewhere; and if it should prove universally indivisible this need not antagonize the idea of a twofold division of the Loess, because owing to elevation, or other causes, there may have been no interstream deposit here contemporaneous with one epoch or the other of the Loess, the deposition of which seems

to have been confined to the vicinity of the river courses at that time.

I may call attention, however, to the fact that in section *c* of the bluff at Memphis, as previously described, a humus stained horizon, indicating an old soil, was found at the upper surface of number 2, but this seemed to me to be the upper surface of the Lafayette, and not a part of the Loess-Loam at that place.

Because of the evident twofold division of the Loess in the north we should naturally expect the same for the Loess in the south, and perhaps for its interfluvial equivalent, the yellow or brownish surface loams. But this does not necessarily follow, for reasons stated above, and the results of my observations, considered without regard to exposures which I have never seen in other localities, will not justify me in an attempt to subdivide the Loess-Loam formation of this region. The formation is, therefore, considered in its entirety and the question of its delimitation discussed more fully in the following paragraphs.

A. *Lower limit of the Loess-Loam.*—This subject has already been discussed more or less fully in the description of the stratigraphic relations of the Brown Loam. The first Glacial epoch is divided by Chamberlin and Salisbury (*Am. Jour. Sci.*, Vol. XLI, pp. 362–363) into two episodes, and the inferior member of the Loess is referred to the close of the second Glacial episode of the first Glacial epoch. From the foregoing evidence it will be seen that the Brown Loam cannot be earlier, and that it is the interfluvial equivalent of at least one, perhaps of both, divisions of the Loess. And neither seems to be the full representative, in the South, of the northern Drift. The Natchez formation was probably deposited during the first Glacial episode of the first Glacial epoch, and towards its close, and I have given reasons above for believing that the same episode is represented in north Mississippi by scattered patches of subaërial deposits. These deposits, as already noted, are composed of local material, and while they may be contemporaneous with the earlier Drift, they are not genetically related to it, as the Natchez formation along the river is said to be.

The Brown Loam and its substratum in many places in this vicinity show a remarkable similarity to the Columbia formation of McGee as described at its type locality. Yet the facts recited above suggest that perhaps the Pleistocene history of the lower Mississippi may not be so simple as he has pictured it. But it is important to note, in this connection, that evidence of a distinct episode between the Lafayette and the Brown Loam is confined to the more inland and higher counties, such as Marshall and Lafayette. Further west such a deposit, if it ever existed, has been removed, and here, too, the Lafayette if it were ever thick has been almôst entirely removed, leaving only a few feet of gravel and sand between the Loess and the Lignitic beds, as is the case at Askew's Bluff, Panola county. In the bluff at Vicksburg, too, in some places, only a few feet of such gravel intervene between the Loess and the Vicksburg limestone of the Tertiary.

Relation of the gravel deposits of north Mississippi to the Loess-Loam.—These gravels, in the main, are considered as primarily belonging to the Lafayette, but in many places they seem to have been worked over and redeposited in the Loess-Loam, or at its base, near their original location. The difference in the stratigraphic position of the pebbles of the eastern and western belts has already been noticed. In the former region, most, if not all, the pebbles have been worked over. These also contain a much higher percentage of chert pebbles—sometimes quite large and angular, or subangular—derived from adjacent Sub-Carbonifereous chert deposits.

The gravels of the western belt are found most frequently at the base of the Loam or Loess. Generally it is not practicable to determine whether they belong to the Loam (or Loess), or whether to the top of the Lafayette. But occasionally a few feet of Lafayette sand intervenes between the gravel bed and the surface formation. At the Memphis bluff, as we have seen, the gravels belong undoubtedly to the Lafayette. At a point eleven miles from Batesville, on the Batesville and Water Valley road, the following relations were observed: A hill mantled

with several feet of loam, which becomes thicker down the hill-side and in the adjacent valley; near the hilltop the underlying Lafayette sands contain scattered quartz pebbles, while further down the hill, at a considerably lower level there is a well-defined pebble stratum at the base of the loam. Toward the hilltop the pebbles are evidently, well within the Lafayette, while toward the bottom of the hill the pebble stratum seems to form the basal member of the Loam, though it is undoubtedly derived from the higher level gravel of the Lafayette (compare the relations of the Loess to certain gravels in southern Illinois *Am. Jour. Sci.*, Vol. XLI, p. 366 *et seq.*).

Similar gravels have been described by Professor Salisbury (JOUR. GEOL., Vol. III, pp. 655–667), from Devil's Lake, Wisconsin, where they underlie the Drift. They are therefore of Pre-Glacial age. Direct correlation of this deposit with the southern gravels is at present impossible, but it seems probable that both were laid down by the same "definitely limited set of agencies" acting within "a definitely limited period of time"—a period closed by the inauguration of the Glacial period in the North.

As to the conditions under which the Lafayette was deposited, I do not feel prepared to speak. However, it seems to me that Hilgard's view as stated in "The Age and Origin of the Lafayette Formation" (*Am. Jour. Sci.*, No. 257, Vol. XLIII), on the whole, is to be preferred; only we must look to another source than melting continental glaciers, for the floods which brought down and deposited the materials of the Lafayette.

B. *Upper limit of the Loess-Loam.*—This formation covers by far the greater part of the surface in this region, and it is only in the "second bottoms" and in the bottoms proper that we find materials of a possibly later age. Many of these "second bottoms" are simply low, broad terraces of degradation carved out of the Yellow Loam, as already noticed. Others are probably stream terraces of constructive origin. But as such deposits are confined to the vicinity of streams, deposition along streams proceeding *pari passu* with erosion of the general surface of the country; and because the materials of such terraces

have been derived wholly or largely from the Loess-Loam, and both formations being usually unstratified, we have no certain means of discriminating the two. And, indeed, the necessity for such discrimination seems very slight when we remember that the formation of these stream terraces began immediately after, or coincidently with, the general uprising which brought the Loess-Loam period to a close; and that they are local lowland deposits formed during a period of general elevation and erosion, rather than general deposits formed during a period of depression. The important point to remember is that the whole of the area under discussion has never been under water since the period of depression during which the Loess-Loam was deposited, and that the interval of general erosion, and "loss of record," which has existed here since the deposition of the Loess-Loam is represented by the contemporaneous deposits of lakes, streams, and adjacent shore lines. Geological history written on tablets of ocean bottom is comparatively easy to read, but written by lakes and rivers upon a scratched and mutilated continental surface, it forms a palimpsest very difficult to decipher by the aid of stratigraphy alone. As an evidence of the truth of this statement I desire to call attention to the different views prevailing among geologists as to the age of the low level deposits known as the Port Hudson group. Some consider this as the oldest of southern Pleistocene formations, others believe that it corresponds to the last epoch of glaciation. With this formation, however, the present paper does not deal, since these deposits are not to be found within the area under discussion. Loess has not been found, I believe, in the North corresponding to the Drift of the third Glacial epoch, yet it does not follow that the Mississippi did not continue to bring down drift material during this time which may have been added to previous deposits of loess or loam.

Nor can we say that this process may not have continued for some time after the final retreat of the ice beyond the Canadian line. If we consider that the Glacial period began in the United States when the land ice from Canada first crossed the

Archæan highlands between Canada and the United States, eroding in some places and in others depositing till; and if the final retreat of the same ice mass beyond the same highlands be considered as marking the close of the Glacial period, how shall we fix the limits of a formation in the south derived largely from glacial débris? Such deposits, no doubt, are still forming to some extent near the edge of the drift-covered area; and the deposit of till in the North must have begun in advance of the deposition of the Loess-Loam, and of the Natchez formation.

We may only say that the Loess-Loam in this region is homotaxial with the drift, that being composed largely of drift materials it cannot antedate the latter and that the two were in a general sense synchronous.

C. *Conditions under which the formation was deposited.*— For a discussion of the conditions under which the Loess-Loam was deposited the reader is referred to *12th Ann. Rep. U. S. Geol. Surv.*, pp. 401–404.

This formation is to be considered as being essentially a flood-plain deposit of glacial débris (worked over to some extent perhaps by the wind), and formed during a period of subsidence, when the whole surface of the country in this region was practically at sea level. The submergence of the surface seems to have been so slight that fresh-water conditions prevailed over marine, and currents laden with glacial débris ran far southward into a tideless bay. Indications, however, of brackish, or of marine conditions, are to be found in the present "salt-licks" which occur quite frequently in the Yellow Loam of some localities, such as Tate and Panola counties.

In the absence of shore lines to mark this incursion of the sea, evidence of submergence is to be found in the areal and vertical distribution of the formation, which no other causes seem competent to explain. Still more direct evidence is afforded by the presence in some localities of huge foreign bowlders imbedded in, or at the base of, the Yellow Loam, and which, it seems, could only have reached their present positions by iceberg action, or through some supernatural agency. A

very interesting deposit of siliceous sandstone blocks is found at Rockyford, Union county, Mississippi, twenty-two miles east of Oxford. Along the hills on either side of Tallahatchie River, near the village, blocks of hard white or gray sandstone either rest directly upon the soil (the prevailing position), or are loosely imbedded in sand. Some of these bowlders will weigh, perhaps, 300 or 400 tons, and many of them present square cut surfaces as if just plucked from some parent ledge. These extend for about one-half mile only on each side of the river. The nearest bed rock at all like these blocks is a Sub-Carboniferous sandstone found in southern Tishomingo county some fifty or sixty miles distant and across the Tallahatchie-Tombigbee divide, on the headwaters of the latter. These bowlders must have been brought down by icebergs from the north, or possibly from the northeast, coming down the Tennessee River valley and across the divide between this and the Tallahatchie, into the latter, where they deposited their load by melting or by overturning.

A smaller block of angular fossiliferous chert, weighing 150 or 200 pounds, was found at the juncture of the Lafayette and the Yellow Loam at a point about seven miles east of Senatobia, in Tate county.

Similar bowlders are reported from other parts of the State, but with these I am not personally familiar.

Absence of stratification in the Yellow Loam may be due in part to its deposition from sluggish currents overloaded with fine detritus (see "Conditions of Sedimentary Deposition," JOUR. GEOL., Vol. I), but the subsequent alteration of the deposit seems generally to have been great enough to have destroyed all traces of stratification which may have existed.

D. *Subsequent alteration.*—In the study of this formation it seems to me that the idea of great chemical alteration subsequent to deposition has not been properly stressed. The fact is evidenced by the present decayed appearance of the loam proper, and by the surface alteration of the loess; by the segregation of part of the lime and iron in the former into "buckshot"

and in the latter into calcareous and ferruginous nodules. At the contact plane of the former with older formations — the Lafayette around Oxford, or the Northern Lignitic a few miles east — there are frequently selvedges of "hardpan," or ferruginous sandstone, sometimes of considerable size, and occasionally containing a high percentage of iron. These are not to be confounded with similar "iron ores" of the Lafayette. That the loess has suffered less alteration than the loam is evident. The present difference between the two may be due partly to original difference in chemical composition and physical texture, but more largely I think to a difference in degree in subsequent alteration. The latter may be attributed to the difference in thickness of the two, which would both give to the loam a higher percentage of organic matter (derived from older soils), which on decomposition would furnish abundant solvent for its soluble constituents, and also allow a freer circulation of water for the accomplishment of the decomposition of putrescible matter and consequent leaching of the loam.

The roots of existing plants, too, may penetrate through the loam as they could not always the loess. But the Memphis sections would seem to indicate, also, original local differences in chemical composition and physical texture.

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CLASSIFICATION OF THE MISSISSIPPIAN SERIES.

Because of its vast array of finely preserved fossil forms, the Mississippian or Lower Carboniferous limestone series, has, since the beginning of geologic investigation in the Mississippi valley, aroused great interest. At an early date the fossils of the successive beds were studied, and were illustrated in the geological reports of Iowa, Illinois, and Missouri, and formation names were given to the various strata. In the final adjustment of the work of all the earlier investigators, the following formation names, from the base upward, came to be recognized, (1) Kinderhook, (2) Burlington, (3) Keokuk, (4) Warsaw, (5) St. Louis, and (6) Kaskaskia or Chester. Each one of these divisions was held to be of equal importance with all the others, essentially, and until recently this original, more or less artificial, classification remained in vogue.

The true classification of rock strata and fossil faunas is but an incident in the elaboration of the geologic history of a region, and in order to make a natural classification of these phenomena, they must be considered from a historical standpoint. The classifications of rock strata which have been generally used, are based upon two distinct sets of criteria, (1) stratigraphic, and (2) faunal. A stratigraphic classification by no means excludes the fossil evidence, and is based fully as much upon the differences observed among the fossil species of successive formations as upon the physical characteristics of the strata; but the fossils are looked upon in the same light as the physical characters, as a sort of label of the strata, rather than as a real life element subject to all the laws of organisms. The old classification of the Mississippian series into the six formations indicated above was purely stratigraphic in its nature, although great stress was laid upon the fossil contents of the various formations.

It is a universally recognized fact today, that assemblages of organisms are intimately related to the environment in which they live. With a change in the environment there will be changes among the associated organisms.

In no geologic province, such as the continental interior of North America during Carboniferous time, whose history must be considered as a unit, are the physical conditions of the whole area identical at any given time. Neither are the conditions of any one limited portion of the province, identical throughout an entire epoch or chapter in its history. Local changes in the physical conditions, and consequently in the local assemblages of organisms are continually in progress. A stratigraphic classification of rock strata is based upon these local changes in the sediments and their contained organic remains, and consequently can be of but local significance. In such a classification the profound physical changes which affect the whole geologic province in its relations with adjacent provinces, are given no greater importance than the comparatively insignificant local changes.

A natural classification of strata must be a faunal classification in its broadest sense. It is based not merely upon the identity or lack of identity of fossil species in the different local formations, but upon the minute study of the relationships of the assemblages of fossils in the successive zones of particular sections, and upon the study of the geographic distribution of species. All fossil species are either indigenous or exotic to the geologic province in which they are found preserved. They are either evolution species or immigration species, and the sudden appearance of exotic or immigration species in the fauna of a geologic province, shows, as nothing else can show, that the relationship between the province and its neighbors is undergoing a readjustment. In the history of any geologic province the distinct epochs or chapters must be limited by these periods of readjustment. Oftentimes these periods cover a considerable lapse of time and alternate with periods of quiet, in which case the periods of change and the periods of quiet are most naturally considered as distinct epochs.

A name applied to a historical epoch of a geologic province, is applicable as a stratigraphic name to all the strata deposited during that epoch. It may not always be possible to draw a sharp and fixed line in the stratigraphic series between two succeeding epochs, so that everywhere, throughout the geologic province the exact limits of the historical epochs may be pointed out. It is not necessary, for the establishment of an epoch name, to select, as the type, a section in which every stratigraphic and faunal phase of the epoch is illustrated. As a matter of fact it would be almost impossible to find a type section for most geologic epochs in which all its varied phases were exhibited. It is only necessary, in the selection of a geographic name for a geologic epoch, that some one or more phases of strata and fauna be well illustrated there.

In recent years, two classifications of the Mississippian series have been proposed. The first by Williams[1] is a natural faunal classification, while the second by Keyes[2] is a stratigraphic classification which is nothing more than a further elaboration of Hall's earlier one, uniting some of his divisions and dividing others.

Williams was the first to recognize in the strata and fossil faunas of the Mississippian series, the evidence of three distinct chapters in the history of the continental interior during lower Carboniferous time, and for these chapters or epochs he used the names (1) Chouteau, (2) Osage, and (3) Ste. Genevieve. The commonly recognized local geologic formations were placed, as accurately as was possible at that time, in their respective epochs, and further investigation seems to necessitate no different disposition of them. Of the three epoch names proposed, Osage and Ste. Genevieve were used for the first time. Chouteau, on the other hand, had long been used as a formation name for one of the local limestone strata in Missouri. The Chouteau group was made by Williams to include, beside the Chouteau limestone,

[1] Bull. U. S. G. S., No. 80, p. 169.

[2] Bull. Geol. Surv. A., Vol. III, p. 283; Iowa Geol. Surv., I, p. 50; and Missouri Geol. Surv., IV, p. 76.

several other local formations, and as the relationship between the faunas of these formations had previously been recognized, and the name Kinderhook applied to them all, it seems best to use the latter name instead of Chouteau for the first epoch.

In order to have a right understanding of the history of the continental interior during Mississippian time, it will be necessary to glance briefly at the events immediately preceding During the greater part of Devonian time, the eastern interior region of North America was occupied by the great Mediterranean Appalachian sea. This sea extended from the Laurentian land on the north to the western extension of the Appalachian land[1] on the south, and from the Appalachian on the east to the Missouri land on the west. The outlines of this sea were continually changing during Devonian time, and at intervals it was joined by open passages in different directions with the outer oceans. Near the close of the Hamilton epoch, a passage through the northwestern portion of North America was opened, by means of which communication was established between the Appalachian sea, and the Eurasian ocean. This northwest passage crossed northern Missouri, Iowa, and southwestern Minnesota, and extended northward through Manitoba and the Mackenzie Valley. The Chemung fauna of the Appalachian province contains an important element derived from the European faunas, an element which without doubt found its way into the Appalachian sea through this northwest passage.

Just before the opening of Mississippian time, the distribution of land and water in North America was about as indicated in Fig. A, the northwest passage being connected with the Eurasian province. The progress of events during the period was, first, an epoch of disturbance, of readjustment and sinking land; second, a long epoch of quiet and equilibrium, with widespread marine conditions; and third, another epoch of disturbance with further readjustment between the interior province and its neighbors. These three epochs are: the Kinderhook, Osage and Ste. Genevieve.

[1] Proc. Bost. Soc. Nat. Hist., XXVI, p. 474; and A. J. S. (4), IV, p. 357.

The stratigraphic elements included in the Kinderhook group are varied in their physical characteristics. There are limestone, sandstone and shale formations. The formations are local in their distribution and characters, and consequently the different minor assemblages of organisms preserved in the strata

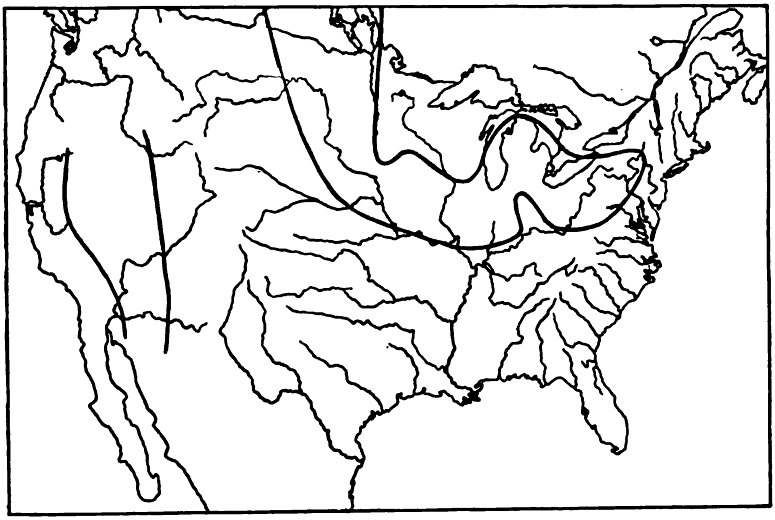

FIG. A.

are more or less local in their distribution. The Kinderkook fauna as a whole is known only in a very general way, no detailed investigation of it has ever been attempted. It is in many respects related to the Devonian faunas, and especially to that fauna which had found its way into the region from the northwest.

During the progress of the Kinderhook epoch the land was sinking to the south, and the southern shore line was migrating in that direction. The margins of the successively younger sediments transgressed further and further to the south over the ancient land surface. In central Missouri, strata of late Devonian age rest directly upon the old Ordovician land surface. In southern Missouri, strata of Kinderhook age occupy the same

position, and in central Arkansas, in the region of the Ouchita uplift, the whole Mississippian series is absent, strata of Lower Coal Measure age resting upon the Ordovician beds.

The Kinderhook epoch of generally disturbed conditions, the epoch of readjustment, was followed by the Osage which was a

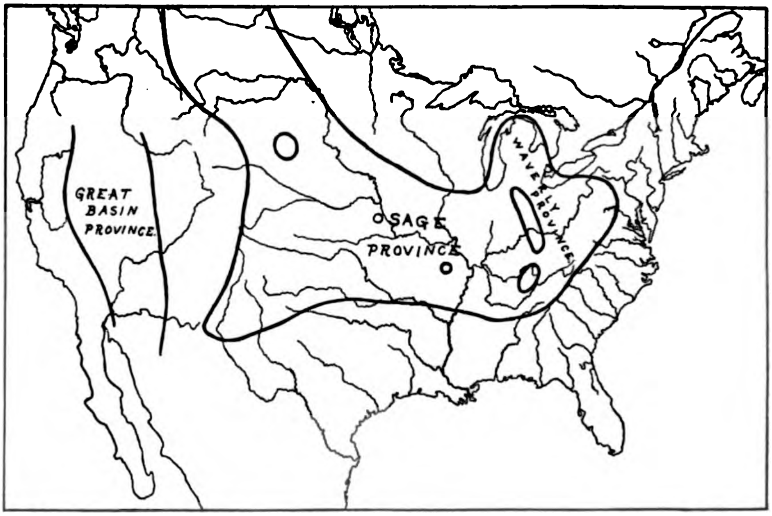

FIG. B.

long period of tranquillity. No longer were there sediments of various sorts being deposited in the interior sea. The surrounding land had sunk so low that practically no sediments were transported by the streams, and the only rock-making material furnished was the calcareous secretions of organisms. Crinoidal fragments constitute the major portion of this limestone, though the remains of corals and brachiopods are also abundant.

The probable distribution of land and water during Osage time is indicated in Fig. B. A great, quiet, interior sea extended from the Cincinnati island on the east to the Rocky Mountain land on the west, and from the southern Appalachian land to the Wisconsin land at the north. The northwest passage still furnished a means of communication with European waters.

The Osage is the best known of any of the Mississippian aunas. Hundreds of species of crinoids founded upon the most perfectly preserved specimens in the world have been described from these strata. Next in importance to the crinoids are the brachiopods, represented by many species. Besides these the corals and bryozoa are often abundant, but the remaining classes of organisms are relatively inconspicuous. The fauna has been most studied in Iowa, Illinois, and Missouri, but a good, crinoidal, Osage fauna has been described from southwestern New Mexico,[1] and crinoids certainly indicating the presence of the fauna have been described from near Bozeman Mountain.[2]

The Osage fauna has many points of resemblance with the fauna of the mountain limestone of western Europe. In each there is a large crinoidal and a large brachiopod element. Every genus of crinoids in the European fauna is represented in the American, and many species of brachiopods are common to both regions, though the American specimens have sometimes been given different names. The following is a partial list of identical or representative brachiopods in the two regions:

American species	European species
Athyris incrassatas H.	*Athyris roissyi* L'Eveille.
A. lamellosa L'Eveille	*A. lamellosa* L'Eveille.
Camarophoria subtrigona M. and W.	*Camarophoria isorhyncha* McCoy.
Chonetes illinoiensis Worthen.	*Chonetes hardrensis* Phill.
Dielasma hastata Sow.	*Dielasma hastata* Sow.
Dielasma sacculus Martin.	*Dielasma sacculus* Martin.
Leptæna rhomboidalis Wilck.	*Leptæna analoga* Phill.
Orthis (Rhipidomella) burlingtonensis H.	*Orthis michelini* L'Eveille.
O. (Schizophoria) swallovi H.	*O. resupinata* Martin.
Productus laevicostus White.	*Productus cora* D'Arb.
P. punctatus S. Martin.	*P. punctatus* Martin,
P. burlingtonensis H.	*P. semireticulatus* Martin.
Rhynchonella pleurodon Phill.	*Rhynchonella pleurodon* Phill.
Spirifer grimesi H. *S. Logani* H.	*Spirifer striatus* Martin.

[1] A. J. S. (3), XXVII, p. 97.

[2] Bull. Ill. State Mus. Nat. Hist., Nos. 10 and 12.

American species.	European species.
S. lineatus Martin. *S. lineatoides* Swall. *S. pseudolineatus* H.	*S. lineatus* Martin.
S. suborbicularis H.	*S. ovalis* Phill.
S. tenuimarginatus H.	*S. duplicicostus* Phill.
Syringothyris carteri H.	*Syringothyris cuspidatus* Martin.

The similarity between the faunas of the two regions is so great that some way of intercommunication must have been in existence. The presence in Grinnell Land[1] of a similar fauna, in some respects intermediate between the two, would seem to indicate a northern and then eastern passage-way between the interior American province and western Europe.

The physical changes, which initiated the interior continental province of Osage time, were of a different nature from the changes that had ushered in previous epochs in the history of the region; and as a consequence, the fauna of the Osage epoch falls into a different category from earlier ones. In no case were the changing faunas of the Appalachian province during Devonian time, to any great extent, indigenous in their origin. The Osage fauna, however, was apparently very largely native to the region. The western European faunas doubtless exercised their influence upon it, but the influence of the American fauna upon that of Europe seems to have been much the greater.

A large portion of the territory occupied by the Osage province had previously been dry land. A vast area of new sea bottom was formed by the sinking of the land. The marine organisms which were to inhabit the region were unhindered in their development. They came in contact with no previously existing fauna which had either to be driven out or to be absorbed into their own social organization. Their rapid growth and differentiation may be compared with the rapid development of a human civilization in a newly opened country with vast resources, where there is a place for everyone with strength and vigor, and where the close struggle of individual with individual does not

[1] Q. J. G. S. Lond., XXXIV, p. 568.

exhaust the vitality. While the close struggle for existence between individuals does seem to be a means of bringing about many minor differentiations of specific importance, the more important differentiations of generic or higher rank seem to be associated with conditions under which there is a wealth of resources, where the struggle is between the organism and the physical environment to a greater extent than between organisms and their nearly related fellows.

The characteristic features of the Osage fauna were assumed at its beginning. After this the struggle was to a greater extent between individuals, and the organic changes were of minor importance, being to a great extent of no more than specific rank.

That the influence exerted by the American fauna upon that of western Europe was greater than the influence of the European upon the American fauna, is shown by a comparison of the crinoidal elements of the faunas in the two regions. In the Osage faunas of America 50 genera of crinoids are recognized, and in the equivalent faunas of western Europe 21 genera. Of the European genera not a single one is peculiar to the region, each being also represented in America. On the other hand 29 genera are peculiar to the American fauna. Furthermore, of the genera which occur both in America and in Europe, a larger number of species are known in America than in Europe. These facts seem to show that as between the two the point of origin or of major distribution of this crinoidal fauna was in the continental interior province of America, and that in the course of its existence it probably migrated from this province into other regions.

During the time when the broad expanse of the clear waters of the Osage sea was the most conspicuous feature of North America, there were in existence at least two other and smaller geologic provinces in which different physical conditions prevailed, and which were inhabited by very different assemblages of organisms. The first of these, the Waverly, lay to the east of the Osage province, between the Cincinnati island and the

Appalachian land, and extended from Michigan through eastern Ohio and western Pennsylvania south to the Ohio River. There was direct communication between this and the western Osage province, and during the Kinderhook epoch there was a considerable community of faunas, but at no time did the clear water conditions of the Osage sea extend into the Waverly gulf. Consequently the clear water Osage species did not generally flourish in the Waverly province, though enough have been recognized to show that the Waverly series is practically the equivalent of the formations of the Kinderhook and Osage epochs combined.

While the interior of the continent was sinking and the Osage sea was spreading out towards the Rocky Mountain land, the land on the northeastern border remained well above sea level. Under these conditions abundant clastic sediments were continuously furnished to the northeastern Waverly gulf, but the long Cincinnati island extending north and south across its mouth prevented the spreading of the sediments into the clear waters of the Osage sea beyond.

In the western part of the North American continent, lying between the Rocky Mountain land on the east and the Californian land on the west, was the Great Basin province. In this province there had been no important change in the passage from Devonian to Carboniferous time. While in the interior of the continent there was but a short interval, the Kinderhook epoch, during which an apparent mingling of Devonian and Carboniferous species is observed, in the Great Basin province Devonian species continued to live, associated with others of Carboniferous types, long after they had disappeared in the Osage province.

Following the prolonged quiet of the Osage epoch in the interior, there was another long period of readjustment and change, which culminated in the elevation of the greater part of the region previous to the deposition of the widespread millstone grit formation which initiated the Coal Measures. This was the Ste. Genevieve epoch. In the far west the barrier

between the Great Basin and the interior provinces was submerged, allowing the incursion of the Great Basin fauna with its persistent Devonian species into the interior. This recurrent Devonian element in the faunas of the interior, first definitely recognized in the Spring Creek limestone from near Batesville, Ark.,[1] is the faunal mark of the initiation of a new chapter in the geologic history of the continental interior. This element is characteristic of the St. Louis fauna wherever it exists. One of the best known of the St. Louis limestone faunas is that of the Spergen Hill beds in Indiana, and in this fauna the recurrent Devonian element is recognizable in the species of *Microdon*, *Conocardium* and *Nuculana*, genera which had disappeared from the interior of the continent during the Osage epoch. Although the Spring Creek and Spergen Hill faunas are quite different in many minor details, they possess many species in common, showing their relationship. In addition to this resemblance of the Spergen Hill fauna to the Spring Creek fauna, which is closely allied to the Great Basin fauna, a fauna practically identical with that of the Spergen Hill beds has been recorded from the far northwest in Idaho,[2] an occurrence which suggests the possibility of its immigration into the interior from that direction.

During the latter part of the Osage epoch there was apparently an emergence of the northern shore line in the region of Iowa, because the younger beds of the Osage group do not extend so far north as the older ones. With the beginning of the Ste. Genevieve epoch, however, this was all submerged again, and the St. Louis limestone strata extended farther to the north than the immediately preceding ones. This submergence was followed by a considerable reëlevation at the north, the Kaskaskia beds being deposited only in the southern portion of the province. The successive changes, more or less abrupt, in the sediments of the Ste. Genevieve group from limestone to sandstone, to shale and back again to limestone, etc., indicate

[1] Am. Jour. Sci., XLIX, p. 94.

[2] A. J. S. (3), V, p. 383.

that rapid and relatively violent local changes were in progress throughout this whole period of readjustment.

The fauna of the Ste. Genevieve epoch in all its varied phases is but imperfectly known, but it apparently contains, throughout, in greater or less degree, the western element suggestive of the prolonged Devonian, which first makes its appearance in the St. Louis limestone fauna, and continues on even into the faunas of the Coal Measures.

In the geologic history of our continent during Mississippian time, many details remain to be elaborated, and with the elaboration of these details our conception of it may be altered in some respects. It is believed, however, that further investigation will but make clearer the general features as outlined here. The threefold classification of the Mississippian strata, based upon the actual geologic history of the region as told by the fossils and by the geographic evolution, is seemingly the only natural one.

An attempt has recently been made[1] to substitute the name Augusta for Osage. The two names have been proposed for practically the same stratigraphic series, but in their proposal the two authors seem to hold very different conceptions of the criteria which should be used when the classification rises above the mere grouping of beds of a local character. The name Osage was proposed for a definitely recognized chapter in the geologic history of the region under consideration, while Augusta was proposed as the name of a special stratigraphic division composed of certain local formations. Hair-splitting distinctions between the exact limitations of groups of beds—however necessary in local and minor classifications—can have no decisive weight in the case, when the higher purpose of major classification, as an expression of the vital features of the history of the region, are duly considered.

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[1] Am. Geol., XXI, p. 229.

EDITORIAL.

AMONG the incidental effects of the war between the United States and Spain will be an awakening to geographic and geologic relations. Even while war was but an anticipation there was not a little brushing up of rusty geography. Now that it is on the study will begin in earnest. And there is need of it. Not a few prognoses of the coming campaign, gravely announced and seriously discussed by the press correspondent, or the public functionary, or the club oracle, have been little less than absurd through their neglect of geographic relationships. Among the masses, and even among people of education, forecasts of quite possible eventualities of the war have been commingled with imagined eventualities which geographic relations altogether prohibit. Even to those fairly well informed the awakenings of the war will bring the rectification of many a false impression and not a little accession of fresh geographic knowledge. Just at this moment when one Spanish fleet is reported to have left Cadiz and another St. Vincent, and their destination is a matter of intense solicitude, it will perhaps come as a revelation to most of us that the Cape Verde Islands are nearer Boston than is Cadiz; that they are nearer Maine than Cuba; that St. Vincent is less distant from every American port on the Atlantic coast than it is from Havana. Both Spanish fleets when they set sail (if indeed they did) were nearer all our Atlantic ports than they were to Admiral Sampson's fleet.

There is, therefore, ample occasion for brushing the dust from our atlases and for the application of rule and compass to them with due regard to the mode of map projection. Beyond question the people of this republic will very generally become better instructed in the geography of the north-central

Atlantic and the north Pacific. They will take a new lesson in geography under the impulse of a grewsome interest and a solicitous intensity not equaled since the early sixties. And the public press with all its faults and errors will become one of the most effective teachers.

But even recourse to the best atlases will leave room for the rectification of erroneous impressions unless used with a circumspection not often realized. Recourse to the globe is to be urgently recommended. Every household which seeks to surround itself with convenient means for promoting an accurate intelligence of the great historical events of the passing days may well provide its living room with a globe—not necessarily large or expensive, for six-inch globes of fair accuracy and detail are in the market at seventy-five cents apiece. Institutions would do well to buy these by the dozen and use them for all sorts of diagrammatic purposes. The globular presentment is the true presentment of the earth; the map is its false presentment in more than a rhetorical sense.

To some extent public interest will extend to geologic factors. The distribution of coal is confessedly a pivotal element in the contest and the natural sources of coal, as well as its commercial distribution, will become familiar to thousands to whom such facts, under conditions of peace, would appeal only with indifference. The special configurations of the American and Spanish coasts are certain to be studied with peculiar intensity. The phenomena of sunken channels, of inlets and harbors, of spits and bars, of reliefs of the land and like features of military significance, will all take on an intensity of interest correspondent to the great issues which may hang upon the aid or the hindrance these features may give in the determination of results.

The actual contact with geographic and geologic phenomena into which the hundred thousand young men, more or less, will be brought as the result of the impending campaign will be to them, and through them to others, a geographic education of no little moment. It was observed at the close of the Civil War

that those who returned from its campaigns possessed an appreciation of the elements of position and physical relationship quite beyond that realized by the preceding generation educated under the benign influences of peace.

These incidental contributions to our favorite sciences and to those elements of education that are associated with them will be among the compensations to be set over against the calamity of war.

T. C. C.

Reviews.

PROFESSOR SPRING ON THE PHYSICS AND CHEMISTRY OF SOLIDS.

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Eine Bemerkung über die Arbeit des Herrn H. Le Chatelier. Zeit. f. Phys. Chem. 9, p. 744

The prime importance to the geologist of all investigations upon the relations of matter and force at great temperatures and pressures makes it profitable, perhaps, to review the work of Walther Spring on this subject. Professor Spring is the pioneer in this field. All his conclusions and theories on the chemistry and mechanics of solid bodies are founded upon a long series of careful experiments, in the course of which he has kept substances under great pressure for periods of more than twenty years, and these furnish us almost the only trustworthy information we have on the subject. It is of especial importance to call the attention of American geologists to this work of Professor Spring, as some discredit was thrown upon his work by M. W. Hallock in a contribution published in *Bulletin 55* U. S. Geol. Survey called "The Flow of Solids, or the Behavior of Solids Under High Pressure." The critic fell into an error through a mistranslation or a misapprehension of the French language,[1] especially translating "se souder" as to melt, and through his failure to grasp the fact that there may be a molecular diffusion in substances in the solid state.

Professor Spring's development of the subject was gradual and followed the advance of his experiments, so that a chronological review of his papers will give us a good exposition of his theories. In his first paper,[2] which was preliminary, he raises the question how sedimentaries harden where there has evidently been no cementation. He states that he has been able to press perfectly dry K NO_3 and Na NO_3 under a pressure of about 20,000 atmospheres into semicrystalline masses harder than the fused substances. Two years later he contributed his first important paper on the subject,[3] which contains,

[1] Simple observation au sujet d'un travail de M. W. Hallock intitulé: "The Flow of Solids," etc. Bull. de L'Académie Royale de Belgique. 3me série, 45, 1887, p. 595.

[2] Note préliminaire sur la propriété les fragments des corps solides de se souder par l'action de la pression. Bull. de L'Académie Royale de Belgique. 2me série, 45, 1878, p. 746.

[3] Sur la propriété que possèdent les corps solides de se souder par l'action de

besides his own valuable results, an excellent résumé of all the different theories concerning regelation. From experiments upon all kinds of chemical compounds he develops the following:

1. All solid bodies tend to consolidate under pressure, and this tendency is a function of the malleability of the substance or, in other words, an inverse function of the internal friction.

2. Pressure aids in consolidating or welding solid bodies because it makes an intimate contact.

3. Bodies capable of assuming crystalline form tend, under pressure, to weld so that the mass has a single crystallographic orientation.

4. Welding under pressure is caused by an actual molecular diffusion in the solid state similar to that in liquids, but far less active.

5. Pressure aids diffusion merely by bringing the particles into intimate contact with each other.

6. The reactions of solids upon solids are equilibrium reactions, and therefore chemical action under pressure tends to go in the direction which gives the smaller volume. Therefore, since the crystalline state is generally that which takes the smallest volume, pressure aids crystallization.

In two succeeding articles he states that solids, as well as liquids[1] and gases, are perfectly elastic volumetrically, that is, upon removal of pressure, the molecules vibrate with the same frequency as before and so the substance assumes its former volume. The only compression he could produce was caused by the crushing in of cavities, etc., and large contraction only occurred where new chemical compounds were formed, as where a new allotropic or polymeric form of the substance was assumed. The statement that matter takes an allotropic state corresponding to the volume which it is obliged to occupy has an exact significance. Moreover, the different states of matter all belong to one series—a liquid is an allotropic form of a gas—a solid of a liquid—a denser solid of a solid of less specific gravity.

This polymerization of molecules accounts for all changes of form and the more dense the polymeric forms, in every case the less active

la pression. Bulletins de l'Académie Royale de Belgique. 2[me] série, 49, 1880, p. 323.

[1] Formation de sulphures métalliques sous l'action de la pression. 3[me] série, 5, 1883, p. 492.

Sur l'élasticité parfaite des corps solides chimiquement définis. Analogie nouvelle entre les solides, les liquides et les gaz. 3[me] série, 6, 1883, p. 507.

are they chemically. This last fact may partially explain the occurrence of chemically active substances uncombined deep within the earth. It is to be noted, however, that temperature acts in an opposite sense to pressure and for every allotropic state there may be a critical temperature above which it cannot exist no matter under what pressure. . . .

In several following papers he explains experiments which confirm his previous conclusions on the diffusion of matter in the solid state. He finds that the velocity of diffusion depends upon three factors: (1) a constant peculiar to each substance and depending upon the velocity of molecular movements; (2) the temperature, with which the molecular velocity increases, and (3) the pressure, which makes the contact more perfect and tends to overcome the "surface tension" of the solid particles. He demonstrates that there is a critical temperature for the change of solids into liquids and mentions cases where liquids by increase of pressure have been changed into solids.[1]

In further experiments he finds that intimate contact caused by constant shaking without pressure causes diffusion between solids, and this diffusion takes place with extraordinary rapidity (three hours) at a higher temperature, though far below the melting point of either substance employed.[2]

In the article "Sur l'apparition dans l'état solide des certaines propriétés caractéristiques de l'état liquide ou gazeux des métaux,"[3] he recapitulates some of his former conclusions and presents new ones as follows:

1. Cohesion between fragments like that between drops of water must be overcome before diffusion between the two can take place.

2. The property of diffusion under pressure is not equally developed in all bodies and is best developed where internal friction is the least and where molecular velocity is the greatest.

[1] Réaction du sulfate de baryum et du carbonate de sodium sous l'influence de la pression. Bull. de l'Académie, etc. 3me série, 10, 1885, p. 204.

Bull. de la Société chimique de Paris, XLI, p. 488.

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Comptes rendus, t. CV, 1887, p. 165.

[2] Sur la réaction chimique des corps à l'état solide. 3me série, 16, 1888, p. 43.

[3] Bull. de l'Académie, etc. 3me série, 28, 1894, p. 23.

Zeit. f. Phys. Chemie.

3. Pressure alone is not so efficient as when accompanied by an agitation of the particles which breaks their cohesion and aids diffusion. This explains cold welding, etc.

4. The three states of matter are only extreme degrees of a single ne and each has a critical pressure and temperature. Solids as well as gases and liquids have faster and slower moving molecules and this variation is the most extreme where the free path is the greatest, viz., at the surface, and therefore solid bodies in contact will weld at their surfaces when below the melting point, due to the interaction of the "liquid molecules."

5. The molecular mobility of a solid body is a function of the proportion of the rapidly moving portion (liquid molecules) to the whole number of molecules.

6. Crystalline bodies have a nearly uniform rate of molecular vibration, and therefore do not "solder" at a temperature much below melting, while amorphous or partially crystalline bodies with heterogeneous molecular motions weld easily.

Finally, in the contributions of the last few years[1] he has described some of his most remarkable experiments on this subject which confirm all his former conclusions. He kept perfectly dry powdered chalk under a pressure of from 6000 to 7000 atmospheres for seventeen years and three months. This same pressure acting through a short time only makes the chalk about as hard as ordinary writing crayon, but after this long time it was found as hard as marble. The fracture was conchoidal and the microscope showed it was crystalline. The steel screw which held the chalk under pressure had completely united to the cylinder, so that the cylinder had to be cut. The chalk was of a yellow ochre color to the depth of 1½^{mm}, showing that the iron molecules had diffused 1½^{mm} into the chalk in about seventeen years.

This diffusion was at the ordinary temperature, but he has shown that at higher temperatures the velocity is much greater and "not only tends to complete the homogeneity of the solid solution, but also to cause an orientation of its molecules." These observations he applies as follows: "Les faits que j'ai observé contribueront peut-être à jeter

[1] Bull. de l'Académie, etc., 3^{me} série, 1895. De l'influence du temps sur l'agglutination de la craie comprimée.

Sur les modifications physiques que subissent certains sulfures sous l'influence de la température. Bull. de l'Académie, 3^{me} série, 1895, p. 311.

Zeit. f. Phys. Chem.

quelque lumière sur la question de la solidification des roches dans la nature. Ils peuvent nous faire comprendre pourquoi, en général, les roches les plus solides et les plus compactes sont aussi les plus anciennes, et ils peuvent nous expliquer la présence de ces milliards de cristaux microscopiques que l'on a observés dans certaines roches, par exemple dans les phyllades, cristaux qui paraissent s'être dévéloppés même après le dépôt des alluvions nécessaires à la formation de ces masses neptuiennes."

And again: "Cette observation ne me paraît pas sans conséquence pour certaines théories pétrographiques. En effet. s'il est déja possible d'observer un changement d'état physique dans un agglomérat après onze années d'exposition à la température ordinaire, il est permis de penser que nombre de phénomènes de crystallization, voire de formation de numéraux, dans les roches agglomerées par la pression, aux dépens de matières à l'état solide, sans qu'il soit absolument nécessaire de faire entrevenir l'action de dissolvants quelconques."

He has also[1] experimented with the compression of dampened powders and finds in general that the insoluble bodies, such as metal filings, etc., do not solidify in the presence of water because the water prevents close contact. Soluble substances act differently—bodies whose solution takes less volume than the water and substance solidify more completely than in the dry state, while those whose solution is attended with an expansion of volume consolidate much better in the dry state. The explanation offered is that when the substance is more soluble under pressure, as pressure is relieved some of the material is precipitated into the interstices of the mass and it is solidified, while in the second case some of the matter is dissolved after the relief of the pressure, leaving a porous incoherent mass.

M. Le Chattilier[2] has noted this same fact that certain bodies in the presence of their saturated solutions solidify under pressure, and explains it a little more in detail as a case of equilibrium under heterogeneous pressure. The water is squeezed out of the mass and therefore is not under so great a pressure as the solid, therefore the solution next to the surface of the solid is supersaturated in respect to that farther away. This water then moving away from the solid precipitates and solidifies the rock.

[1] Zeits. für Phys. Chem., 2, p. 532. Über die Kompression von feuchter Pulver fester Körper und die Formbildung der Gesteine.

[2] Zeits. für Phys. Chem., IX, p. 335.

It has long been known that rocks suffer actual molecular movement if the forces act so slowly that they do not overpass the elastic limit of the rock, and again bodily movement must take place if the rock is subject to stresses greater than the ultimate strength of the rock, but the knowledge of the fact that solid matter has so much in common with gases and liquids is almost wholly due to the laborious investigations of Professor Spring, and these facts should immediately take their place in our theories of the condition of matter in the interior of the earth. C. F. TOLMAN, JR.

United States Geologic Atlas, Folio 37. Downieville, California. 1897.

This folio consists of eight pages of text signed by H. W. Turner, geologist, a topographic map of the district, a map showing the areal geology, a map showing the economic features, a structure section sheet, and one page of special illustrations.

The quadrangle represented in this folio lies between parallels 39° 30′ and 40° north latitude, and 121° and 120° 30′ west longitude. It comprises a portion of the northern Sierra Nevada and lies in Plumas and Sierra counties. The area is drained by the forks of the Feather and Yuba rivers.

The formations are divided into two main groups, the bed-rock series and the superjacent series. The bed-rock series is composed of Juratrias and Palæozoic sediments and tuffs, and a series of old igneous rocks chiefly granites and porphyries. The Juratrias rocks comprise chiefly the Milton formation which is found only in the southeast portion of the quadrangle. The Milton formation, while formed of materials deposited under water, contains a large amount of igneous material. Underlying the Milton formation there are volcanic beds which are likewise presumed to be of Juratrias age, inasmuch as in the lower portion there are lenses of siliceous argillite, in one of which an ammonite was found. These volcanic beds are grouped as quartz-porphyry and as augite-porphyrite. The quartz-porphyry also occurs as dikes. The other igneous rocks forming part of the bed-rock series are granite, gabbro, and granodiorite. In the western portion of the quadrangle there are very large amounts of serpentine which have resulted from the decomposition of the pyroxene olivine rocks or peridotites and amphibolite which is the result of dynamo-metamor-

phism and hydro-metamorphism of augite-porphyrite. The rocks of the auriferous slate series comprise, besides the Milton formation just noted, an older set of rocks probably largely of Carboniferous age, as fossils of that age only have been found in them. These Carboniferous rocks are divided into two formations, the Robinson formation of late Carboniferous or possibly of Permian age, and the Calaveras formation, comprising rocks probably older than the Robinson formation.

The superjacent series consists of river slake deposits, moraines, and volcanic material. All of the rocks of the bed-rock series, both slates and igneous rocks, were greatly eroded during Cretaceous time and upon this old eroded surface there has been deposited by rivers of Tertiary age an extensive series of gravels, known as the auriferous gravel series. The river system of Tertiary time appears to be divisible into two distinct drainage systems with a divide between. This divide is represented by the high ridge of which the Sierra Buttes is the culminating point. The rivers to the west of this high north-south ridge drained southerly or southwesterly in Tertiary time as they do now. The deposits to the east of this Neocene divide appear to have been deposited by one large river which flowed north, draining into a basin to the north of the quadrangle. Superimposed upon these gravels, and at other points upon the older bed-rock surface, are extensive deposits of lavas, mostly in the form of breccias which have been very largely eroded. At one time these lavas probably covered nearly the entire surface of the quadrangle. They consist chiefly of andesites and basalts. The latest basalts, notably the kind forming the larger portion of Mount Ingalls, are possibly of early Pleistocene age. After the volcanic forces had subsided, portions of the region were occupied by glacial ice, resulting in the formation of very extensive moraines, which are finely seen on the east slope of the Sierra Buttes, about Gold Lake, and in the neighborhood of Johnsville. All of the lakes that lie on the east slope of the high ridge extending from the Sierra Buttes to Eureka Peak, are of glacial origin.

There are evidences of faulting in Tertiary and later time at various places in the district. The largest fault zone is that lying immediately west of Mohawk Valley. The faulting along the south and west sides of the American Valley, may perhaps be correlated with the same fault zone. As a result of this faulting the country to the east of the fault zone has subsided, resulting in the formation of the Mohawk and American valleys. Mohawk Valley, during early Pleistocene time,

was occupied by a lake which has left terraces about the valley. These are finely preserved on the slope west of the north end of the valley.

Economic geology.— As economic features there are represented on the map numerous lenses of limestone, which is often highly magnesian. Gold quartz veins are indicated by orange dashes. The auriferous gravels are noted, and also deposits of chrome iron and of magnetite.

Bulletin of the American Museum of Natural History. Vol. IX, 1897.

This volume contains twenty-four separate articles contributed by members of the museum staff. Those from the departments of vertebrate and invertebrate palæontology will be briefly noticed.

Article IV. *Note on the Hypostome of Lichas (Terataspis) grandis* Hall. By R. P. WHITFIELD, pp. 45–46.

Lichas (Terataspis) grandis, is one of the largest and most highly ornamented trilobites of the Devoinan faunas. As yet it has never been found preserved except as fragments, and previous to the present paper no hypostome of the species has been described. This note by Professor Whitfield describes, with illustrations, two large hypostomes supposed by him to belong to this species. They are from loose bowlders of Schoharie grit obtained in northern New Jersey and are associated with other fragments of the same trilobite and with other species of the same horizon.

Article VI. *The Ganodonta and their relationship to the Edentata.* By J. L. WORTMAN, pp. 59–110.

The relationship of the Edentate mammals has long puzzled zoölogists, and previous to the establishment of the suborder *Ganodonta* by Dr. Wortman, no palæontologist has more than suggested what this relationship might be. Although the genera composing the group have long been known, yet the materials, up to the present time, have been so imperfect and fragmentary as to preclude any very exact knowledge of their affinities, and they have been placed by different authors at different times with the *Tillodontia*, the *Tæniodonta*, and the *Creodonta*. By the aid of the discovery of a fore limb of one of the species, *Pisittacotherium multifragum*, in association with the lower jaw and

upper teeth, Dr. Wortman has been enabled to interpret the somewhat fragmentary remains of the other genera and to make out what he believes to be, not only their affinities to each other, but what is still more important, to demonstrate their genetic relationship to the later appearing American *Edentata*.

The genera included in the suborder are *Conoryctes*, *Onychodectes*, *Hemiganus*, *Pisittacotherium*, *Calamodon*, and *Stylinodon*. In the treatment of the relationship of these genera to the *Edentata*, seventeen points of resemblance are enumerated, and they are considered as a primative suborder of and the ancestors of the Edentates.

The South American Edentates appear suddenly in the Santa Cruz formation in great numbers and variety with apparently no previous announcement in the older deposits. This fact would seem to indicate that they were immigrants from another region. While the Santa Cruz beds cannot yet be accurately placed in the time scale, it is highly probable that they are not older than the North American Oligocene. In North America the *Ganodonta* appear in the very earliest Puerco deposits and continue without interruption into the Bridger, where they disappear.

If Dr. Wortman's conclusions as to the relationship of the *Ganodonta* to the *Edentata* be correct, as they seem to be, the geographic distribution of the groups would suggest that during Eocene time there was at least a temporary connection between the North and South American continents, allowing the immigration from the north, of the ancestors of the South American Edentate fauna.

Article XI. *Description of New Species of Silurian Fossils from near Fort Cassin and elsewhere on Lake Champlain.* By R. P. WHITFIELD, pp. 177–184. Plates IV–V.

The fauna of the Fort Cassin beds on Lake Champlain is one of remarkable interest. Its position is in the Lower Ordovician, in the upper part of the Calciferous formation. As a rule the Calciferous strata do not furnish an abundance of fossils, either specifically or individually, but the Fort Cassin beds are an exception. Two previous papers containing descriptions of species from this bed by Professor Whitfield[1] have appeared, so that in all 60 species are now known, distributed as follows, 25 gastropoda, 17 cephalopoda, 8 trilobites, 7 brachiopoda, 2 crustacea (not trilobites) and 1 bryozoan.

[1] Bull. Am. Mus. Nat. Hist., I, p. 293, and Bull. Am. Mus. Nat. Hist., III, p. 25.

Article XII. *Descriptions of species of Rudistæ from the Cretaceous Rocks of Jamaica, W. I., Collected and Presented by Mr. F. C. Nicholas.* By. R. P. WHITFIELD, pp. 185–196. Plates VI–XXII.

This papers contains descriptions with excellent illustrations of ten new species of these interesting fossils from Jamaica. Six species are referred to the genus *Radiolites*, and four to *Caprina*.

Article XX. *Observations on the Genus Barrettia* Woodward, *with Descriptions of New Species.* By R. P. WHITFIELD, pp. 233–246. Plates XXVII–XXXIII.

The genus *Barrettia* was established by Woodward, upon some peculiar cup-shaped fossils from the Cretaceous limestone of Jamaica, W. I., and was referred by him to the *Rudistæ*. Since the original description several authors have expressed doubts as to the correct reference of the genus to this group, and have questioned its molluscan nature, considering it to be more probably a coral.

Professor Whitfield's investigation of the genus is based upon a collection of these fossils, some of them of large size, sent to the museum by Mr. F. C. Nicholas. All of the characters, some of which were not observed by Woodward, are carefully summed up and the conclusion is reached that they are most probably corals. The paper is concluded by the description of two new species.

Article XXI. *The Huerfano Lake Basin, Southern Colorado, and its Wind River and Bridger Fauna.* By H. F. OSBORN, pp. 247–258.

The presence of Eocene beds in the Huerfano River basin of southern Colorado, was first made known, in 1888, by Professor R. C. Hills, of Denver. Three papers, published between 1888 and 1891, record the results of his observations upon the region. In the course of his investigation, the Huerfano series was divided into three divisions, beginning from the top as follows, (1) Huerfano beds 3300 feet, (2) Cuchara beds, 300 feet, and (3) Poison Canyon beds 3500 feet. The Huerfano beds were correlated with the Bridger group or Middle Eocene, on the basis if the vertebrate remains discovered, and the two lower divisions were provisionally referred to the lower Eocene from their stratigraphic position, no fossils being found.

At a later date the region was visited by Professor Osborn and Dr. Wortman, and the present paper records the results of their observations.

The two lower divisions, the Cuchara and Poison Canyon beds, were found to lie unconformably below the Huerfano beds, and from the presence of a species of *Baculites* it is supposed that they are Cretaceous deposits of marine origin. These Cretaceous beds were found to be certainly not 800 feet below the summit of the upper Huerfano beds, so that the observation affects not only the determination of the age of the Poison Canyon and Cuchara beds, but materially reduces the thickness of the upper beds.

The only true Huerfano lake deposits are variegated marls, clays, soft shales and sands, aggregating only 800 to 1000 feet in thickness, and lying in a nearly horizontal position. In these beds, although without doubt forming a continuous deposition, two distinct horizons were identified from their inclosed vertebrate remains. The upper one of these horizons, the one from which Professor Hills secured the major part of his material, is of Bridger age. The lower horizon, however, contains none of the forms characteristic of the Bridger level, but is distinguished as of Wind River or of Wasatch age, by the presence of several characteristic lower Eocene forms.

Article XXII. *A Revision of the Puerco Fauna.* By W. D. MATTHEW. Pp. 259–323.

The Puerco fauna was first described by Cope in numerous papers published between 1881 and 1888. Ninety-one species of mammals were recognized, and to these three more were added by Osborn and Earle in 1895. The original collections used by Cope are now the property of the museum, and to these have been added important collections made by the museum expeditions in charge of Dr. J. L. Wortman. The present revision is based upon all of these collections, and consists largely in a rearrangement of the species and a reduction of their number, made possible by the more perfect material.

The fauna of the upper Puerco beds is found to be entirely distinct from that of the lower beds, not a single species being common to both, and in no case does a genus pass through without serious modification of at least subgeneric value. Because of this difference in the faunas, Dr. Wortman proposes to designate the upper beds by the name Torrejon formation.

The Puerco-Torrejon faunas are composed of the following elements:

1. The Mesozoic group of Multituberculates culminates in the

Puerco and dies out in the Torrejon, true Rodents coming in to take its place.

2. The main body of the fauna is composed of primitive types from which sprang the Ungulates on the one hand and the later Creodonts and Carnivores on the other. In the Puerco these two divisions are hardly distinguishable, but in the Torrejon they are clearly separable, although still closely allied.

3. A few more specialized lines, the Edentata, Amblypoda and Rodents, with a fourth type allied to the Primates, may be separated from the main group.

A total number of seventy-five species is recognized in the whole fauna.

STUART WELLER.

AUTHORS' ABSTRACTS.

ABSTRACT OF PAPER READ AT THE MONTREAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA.

Weathering of Alnoite in Manheim, N. Y. By. C. H. SMYTH, JR.

A somewhat altered dike of alnoite, consisting of biotite, serpentine, magnetite, perofskite, apatite, and some calcite, is exposed on the east bank of the East Canada Creek. Melilite, abundant in two neighboring dikes, is not apparent, doubtless being obscured by alteration.

On the west bank the dike is weathered to a fine yellowish-brown sandy clay, exposed about fifteen feet vertically. Under the microscope, the weathered material is seen to consist chiefly of biotite, magnetite, and perofskite, the other minerals being no longer recognizable.

From chemical analysis, it is evident that the rock in weathering has lost about 27 per cent., chiefly silica and magnesia, with less lime and potash. Alumina and titanic oxide show a relative gain in the same ratio, and are assumed to have remained constant. Iron also shows a relative gain, but slightly less than that of alumina, while it has undergone much oxidation. The amount of water has been very largely increased.

The greatest percentage of loss for a single constituent (excepting CO_2, which has totally disappeared) is shown in the case of potash, of which 92.27 per cent. has been removed. Soda has lost about 75 per cent., magnesia, 49 per cent., lime 45 per cent., silica, 27 per cent., and iron oxide less than 4 per cent.

The process of weathering has involved this considerable solution, together with oxidation and hydration. The accompanying physical changes are a complete change of color, and a disintegration so thorough that the material may be easily scooped out with the hands.

The contrast between alteration and weathering is pronounced. The former led to the formation of serpentine and calcite, without

oxidation. Weathering, on the other hand, destroyed both of these minerals and effected much oxidation. The first process could hardly be regarded as destructive, the last is eminently so.

The weathered dike occurs in the nearly vertical rock wall of the creek gorge, which is doubtless of postglacial origin. As the dike, in its present condition, would offer almost no resistance to the attack of the stream, it is evident that in the first stages of gorge cutting the rock must have been nearly or quite unweathered. From this it follows that the weathering, as now seen, has been accomplished in postglacial time.

THE

JOURNAL OF GEOLOGY

MAY-JUNE, 1898

A SYMPOSIUM ON THE CLASSIFICATION AND NOMENCLATURE OF GEOLOGIC TIME-DIVISIONS.

THE infelicities which arise from the uncertain use of terms in the discussion of geologic time-divisions are more or less fully appreciated by every working geologist. The peculiar difficulties which the varying and often inconsistent use of terms imposes upon the student of geology when he leaves the narrow confines of his text-book and tries to use the current literature of the science, can only be realized by those teachers who have encouraged this broader method of study and conscientiously feel responsible for the results. Not every text-book, even, is consistent with itself. It is too much to insist that it should be consistent with general usage until a consistent general usage is established. The importance of a more systematic classification of time-divisions and rock-series has been recognized by the international congresses of the last two decades. The limited results that have been reached by the efforts of these congresses seem to indicate that the problem must be worked out by gradual approaches through tentative efforts. It perhaps also indicates that the problem must be in large part worked out in the great provinces or in the individual continents separately as a preliminary to intercontinental coördination. Not a few geologists who heartily sympathize with the effort to secure more uniform and better practice are yet quite unwilling to have a rigid system imposed by the vote of a body of so uncertain composition as

an international congress. Quite aside from doubts connected with such an enacting body, there are those who question whether we have reached that stage in the development of interpretations and correlations which warrants the formal adoption of a universal system of classification and nomenclature. Fully sympathizing with both these classes, we none the less feel that these considerations only emphasize the importance of those preliminary and tentative efforts through whose agency a satisfactory system is to be worked out in time by the method of concerted trial and continued rectification. Especially does it seem important to proceed as fast as may be with the evolution of a system appropriate to our own continent as a preliminary to the establishment of an intercontinental system.

Certain phases of a system of nomenclature involve little more than a choice of terms. To this extent only a consensus of preference is needed to inaugurate a common practice which shall become conventional. In most cases, however, the choice of terms is connected with a choice of ideas, and a consensus is less readily reached. Whether a community of preference can now be reached or not, it can scarcely be questioned that we should work toward such a community, if possible, rather than away from it. We appear to have been receding from uniformity, rather than approaching it, for the past two decades. The result is a disturbed practice and a confusion of terms infelicitous alike to geologist, to teacher, and to student.

The more important phase of the question lies back of the selection of terms and relates to the questions: What divisions, or what order of divisions, shall be chosen for formal nomenclature, and upon what criteria shall the divisions be determined? Granting that these questions cannot be answered finally at present, or in the near future, it is still urgent to inquire: By the use of what system, provisionally adopted for current use, can we best work on toward better systems in the future?

To draw out opinion on the subject, a series of questions was prepared by one of the editors of this JOURNAL (Professor Salisbury) and submitted to several American geologists with a

view to inaugurating discussion. The questions were made specific to invite definiteness in the replies. They were made to overlap somewhat to facilitate specific answers to different aspects of the subject. It was not intended to specifically advocate the scheme presented, but merely to submit a tangible sketch for discussion. A portion of the replies are printed in this number. The discussion of the subject by others who may be interested is invited. The questions submitted are as follows:

1. What classification of time (and terranes), say to the third or fourth division, seems to you best adapted to North America? If you are ready to express your opinion concerning such a classification to the second division, but not farther, please do so.

2. To what extent is it desirable to adhere to European standards, if some other classification is better adapted to North America?

3. What noun should be used in connection with the adjectives *Palæozoic*, *Mesozoic*, etc., 1° when time is meant, and 2° when formations are concerned? For example, Palæozoic *era?* Palæozoic *group?*

4. What noun should be used in connection with the primary subdivisions of the Palæozoic such as Cambrian, 1° when time is meant, and 2° when formations are concerned? For example, Cambrian *period?* Cambrian *system?*

5. What is the best noun to be used in connection with divisions of the third order, such as Lower Cambrian, Middle Cambrian, etc.? For example, Lower Cambrian *epoch?* Lower Cambrian *formation?*

6. Ditto for divisions of the fourth order.

7. Would you approve of the separation of the sub-Carboniferous and the Permian as divisions coördinate with the Carboniferous proper, the Devonian, etc.

8. If you approve of the separation of the sub-Carboniferous from the Carboniferous, as a division of the second order, would you approve of retaining the name sub-Carboniferous or Lower Carboniferous, or would a new name be better, say Mississip-

pian? The repetition of terms involved, if the term sub-Carboniferous or Lower Carboniferous and Carboniferous continue to be used as now, is so great as to be very confusing to students. Those who have not dealt with students beginning the study of historical geology may not be aware of the difficulty involved in such a system as the following:

Carboniferous,
  Permian,
  Carboniferous,
  Sub-Carboniferous.

9. Would you approve of the separation of the Cretaceous into two divisions coördinate with each other, and each coördinate with such divisions as the Devonian?

10. If so, would you approve of the retention of the names Lower Cretaceous and Upper Cretaceous, or should one of these divisions, presumably the Lower, receive a new name, say Comanche?

11. How should the Cenozoic be subdivided?

12. What is the advantage of the term *Canadian*, and the corresponding *Trenton*, in the following classification?

Ordovician - -	Trenton	Hudson River
		Utica
		Trenton
	Canadian	Chazy
		Calciferous

Why not instead?

Ordovician - - -	Hudson River
	Utica
	Trenton
	Chazy
	Calciferous

13. Will you express your opinion concerning the following outline where the divisions are carried to the second order?

Era (for time) Group (for rocks)	Period (for time) System (for rocks)
Cenozoic - -	Pleistocene
	Pliocene
	Miocene
	Eocene

Mesozoic - -	Cretaceous (Upper) Comanche (Lower Cretaceous) Jurassic Triassic
Palæozoic - -	Permian Carboniferous Mississippian (sub-Carboniferous) Devonian Silurian Ordovician Cambrian
Proterozoic - -	Keweenawan Upper Huronian Lower Huronian
Azoic - -	Archæan

14. What would you say to this plan of classification:

Era - - -	Group
Period - - -	System
Epoch - - -	Series
Stage - - -	Formation

CONTRIBUTION BY JOSEPH LE CONTE.

I hereby give answers to your questions as briefly as possible:

1. I am not prepared to go further than divisions of the second order.

2. European standards, as first in the field, must be followed as far as possible, but should be modified, if necessary. But eventually we must have a world standard, at least for divisions of first and second orders.

3. I think—Era and Group are best.

4. " " Period and System are best.

5. " " Epoch and Series are best.

6. " " Stage and Formation are best.

7. (*a*) *Sub-Carboniferous* is certainly coördinate with Carboniferous proper, but I do not think that *Permian* is. Witness the tendency to unite Carboniferous and Permian under Permo-Carboniferous.

(*b*) But I much doubt that these are coördinate with *Devonian*.

8. "Mississippian" serves our American purposes well, but, if used, ought to be coupled with Lower Carboniferous as synonym, as you have done.

9. Cretaceous ought to be divided into two coördinate divisions, but I do not think these are at all coördinate with Triassic, Jurassic, or Devonian. They must be regarded as sub-periods.

10. I think it best, therefore, to retain the names Lower and Upper Cretaceous; but, if a new name is used for the lower division, why not call it "*Shasta*." It was certainly first recognized there.

11. I am in favor of the fourfold division of Cenozoic you propose, although I fully appreciate the reasons for uniting Miocene and Pliocene into Neocene. Tertiary and Quaternary might well be abolished, as Primary and Secondary have already been.

12. I see no sufficient reason for the names Canadian and Trenton as sub-periods. Better divide Ordovician at once into epochs, as you suggest.

13. I like your schedule of divisions of first and second orders except as regards the Cretaceous and Carboniferous, as already explained. Also, I do not like the term "Azoic," although not prepared to suggest anything better.

14. I fully endorse your general plan of classification for time and strata. JOSEPH LE CONTE.

CONTRIBUTION BY G. K. GILBERT.

So long as historical geology continues to be a living science no definite system of nomenclature can hope to be permanent, nor even, perhaps, to give temporary satisfaction to a majority of geologists. Nevertheless, as intimated by the JOURNAL's circular letter, teachers and geological surveys must have definite systems, and so the task of making and remaking them is a sort of necessary evil.

(Questions 1 and 2.) Though time is universal, faunas and histories are more or less local. A refined time scale cannot be used to advantage in the correlation of formations widely separated. Therefore, only the major orders of a time classification should be treated as universal, and the minor should be recognized as local. I suggest that the line of discrimination be arbitrarily drawn between divisions of the second and third ranks, periods and epochs.

Pursuant to this suggestion, I propose the following auxiliary criterion for periods (not replacing but supplementing other criteria): Periods should have such magnitude that their application to the correlation of formations anywhere in the northern hemisphere will yield areas of certainty which are large as compared to the unavoidable zones of doubt.

This criterion is used in the selection of the subjoined scheme of periods, but is subordinated to other considerations in the admission of Pleistocene and Algonkian. Jurassic and Triassic are given separate place despite their broad zones of doubt when applied to American terranes, because the breadth of those zones is due to dearth of the most important data for correlation, marine fossils.

Periods.

12. Pleistocene (or Quaternary).	6. Devonian.
11. Tertiary.	5. Silurian.
10. Cretaceous.	4. Ordovician.
9. Jurassic (or Jura).	3. Cambrian.
8. Triassic (or Trias).	2. Algonkian.
7. Carboniferous.	1. Archæan.

(3.) Four time-nouns have been used in this rank by various authors: *Era*, *age*, *eon*, and *time*. *Time* cannot be spared from its general sense. Of the others *eon* alone has a good connotation for this place; its untechnical meaning always includes long duration.

Group is not well placed in this rank. Prevalent American usage, which puts it next above the unit *formation*, is in harmony

with the ordinary meaning of the word,—an aggregate of individuals (not an aggregate of aggregates).

(7.) No.

(7, 8.) I like Mississippian as the title of an American subdivision of the Carboniferous period. There is need of a complementary, coördinate, American, geographic name (or names).

(9.) No.

(14.) I prefer:

Eon - - -	System (or Series).
Period - - -	Series (or System).
Epoch - - -	Group.
Stage (or Age) -	Formation.

(Comment on 5, 8, 10, 13.) The adjectives of space relation, *Lower* and *Upper*, should not appear in a time scheme. The prefixes *Eo-*, *Meso-* and *Neo-* (proposed for a somewhat different use by Williams) seem appropriate for the indication of indefinite portions of any time unit. For definite parts separate geographic names are preferable. G. K. GILBERT.

CONTRIBUTION BY WM. BULLOCK CLARK.

I think that the questions, which you have raised regarding the use of terms in geological classification, are most timely. If a discussion of the subject can aid in bringing about some unanimity in the employment of these terms on the part of geologists, you will have performed a great service.

I am inclined to take the position that, from the very nature of the case, a universal system of stratigraphic equivalents cannot be employed for the chronologic terms. The chronologic divisions, as we all recognize, are at best highly artificial, while the stratigraphic divisions are natural and definitely determinable units. The term "formation," for example, has come to be rather widely used to embrace deposits formed under approximately similar conditions whatever the time element involved, and may or may not be separated from overlying or underlying formations by an unconformity.

Accepting the chronologic terms which you have adopted,

and which, I think, cannot be improved upon, certainly to the third division—viz., era, period, epoch—it may be possible to find the formation as the equivalent of a portion or the whole of any one of these time divisions, excepting, perhaps, the era. To attempt to restrict it, therefore, in all instances to any chronologic division, large or small, would seem to me unwise.

Furthermore, I think that a different series of names should be applied to the formations and their subdivisions than to the time units. I should speak of the Palæozoic era or time, the Cambrian period, and the Upper Cambrian, or better, the Neo-Cambrian epoch, but of the Potsdam formation or the Shenandoah formation, the latter representing portions of the Lower Silurian as well as Upper Cambrian, and affording a good example of the formational unit. I prefer the prefixes Eo-, Meso- and Neo- to designate the epochs, as proposed by Williams. I think the term Stage more applicable to a division of a formation, whether characterized by a distinct fauna or not, than to a time unit.

In reply to your questions seven and eight regarding the later divisions of the Palæozoic, I should employ the chronologic terms Carboniferous and Permian, the former divided into Upper and Lower, or Upper, Middle and Lower Carboniferous, as the case might be. To be consistent the terms Eo-, Meso- and Neo-Carboniferous should be used. The Upper Carboniferous may be represented by Coal Measures made up of one or more formations; the Lower Carboniferous may be represented as in the central United States, by the Mississippian, or, as I should prefer, the Mississippi Group, made up of various formations. I should personally object to the use of the term Mississippian in a chronologic sense, unless the period term Carboniferous was to be permanently divided and the resultant divisions raised to the period rank. The reasons for such change, however, do not seem to me to be sufficiently strong. I think the widely extended difference in facies represented in the Upper and Lower Carboniferous tends greatly to accentuate the two divisions of this period.

These same reasons seem to me to apply equally well to the Cretaceous. Although there is a very considerable difference between the upper and lower divisions, it does not seem to me sufficiently great to warrant their elevation to equal rank with Devonian, Carboniferous, etc. I should, therefore, employ Comanche in its original sense as a stratigraphic term, and, as several formations are clearly recognized within the limits assigned to it, I should be inclined to speak of the Comanche Group.

I should prefer to divide the Cenozoic into Eocene, Neocene, and Pleistocene as the most widely recognizable time units, placing under the earlier term Eocene the subsequently named division Oligocene of von Beyrich and uniting Miocene and Pliocene into Neocene.

I can see little advantage in the use of the terms Canadian and Trenton, except as group names, to include the Calciferous and other formational divisions.

I prefer the use of Lower Silurian to Ordovician, as I do not think the term Silurian of Murchison can with propriety be restricted to the Upper Silurian. If the Upper and Lower Silurian are to be raised to period position, and Ordovician used, I think some other name should be substituted for Silurian.

WM. BULLOCK CLARK.

CONTRIBUTION BY S. W. WILLISTON.

I am greatly pleased with your attempt to reduce some kind of order out of the chaos that has been made in geological nomenclature. I think no one but the actual teacher of historical geology can appreciate the amount of confusion that now exists and the vexation that it causes both teacher and pupil.

To the first five questions I am not prepared to offer suggestions except this, that it will make very little difference what terms are used for the time and formation, provided there is uniformity. I am ready to accept and teach any system that receives the approval of writers on these subjects, and is used with tolerable fixity and uniformity.

7. To this proposition I would desire to enter a vigorous protest. Having worked in Kansas, where the Permian is best represented in this country, I can see no good grounds whatever for distinguishing between two groups in respect to which neither the palæontologist nor the stratigraphist can determine where the one begins and the other ends. Palæontologically there is nothing of sufficient importance to warrant the division into primary periods. It is true that, so far as we now know, the reptiles began in this time, but every palæontologist confidently expects that they will be found in the true Carboniferous, and in fact they have been found in Kansas in strata that are yet in dispute. Knowing less of the sub-Carboniferous, I cannot give an opinion here, but I do not believe there are any better grounds for division than between the Carboniferous and the Permian.

Classification of the time periods of the earth must inevitably follow the same rules as those applied in the classification of animals and plants, which in the end becomes one of convenience, chiefly. If we increase the number of primary divisions, as the tendency seems to be, the number will at last become so large that some future classifier will insist upon reuniting many of them under new and undesirable names. The chief divisions should represent, so far as possible, time periods of equivalent importance, and to say that the Permian period is an equivalent of the Carboniferous, or the Silurian, is certainly incorrect. Personally, I would rather see the Trias annexed to the contiguous divisions!

8. I should much prefer to see the name Carboniferous applied to the primary division and distinctive names given to the three subdivisions. There is a *very* great, almost intolerable, objection to using the name Carboniferous in two senses, or even the Carbonic and Carboniferous. I very much hope that the name Mississippian may be given to the lowest group, some good distinctive term to the intermediate, as Coal Measures, and Permian applied to the uppermost.

9. For many of the same reasons already given for the

Permian, I strenuously object to the subdivision of the Cretaceous into two primary divisions. Certainly, so far as vertebrate palæontology is concerned, there is no good reason for the division, and there are many opposed to it. I would rather prefer Upper and Lower, for the divisions of the Cretaceous, but would willingly see such terms as Platte and Comanche used.

11. I would prefer to have the Cenozoic divided into the Eocene, Miocene, Pliocene and Pleistocene. I believe this is the only logical system, unless, perhaps, the Oligocene is added. Nevertheless, I see great difficulty in superseding the much used Tertiary. Most assuredly there should be no distinction into "Tertiary" and "Quaternary," and, if Tertiary is used, its limitations must be widened to include the Pleistocene. This will be equally hard to do, and for that reason I believe, upon the whole, the best way is to drop the term Tertiary entirely.

14. I am quite ready to use the plan of classification given in my teaching and writings, if its use can become at all general. Fixity and uniformity are all that I ask for here.

13. The terms and divisions that I think ought to be adopted, so far as I have grounds to base my opinions upon, are as follows:

Cenozoic, - - -	Pleistocene,	
	Pliocene,	
	Miocene,	
	Eocene,	
Mesozoic, - -	Cretaceous,	Upper. Lower.
	Jurassic.	
	Triassic.	
Palæozic, - - -	Carboniferous,	Permian. Coal Measures. Mississippian.
	Devonian,	
	Silurian,	
	Ordovician,	
	Cambrian.	
Eozoic or Proterozoic,		
Azoic.		

I have done very little field or laboratory work upon the divi-

sions prior to the Carboniferous and refrain from expressing an opinion about them.

I very much prefer the use of European terms for divisions that can be correlated with tolerable exactness; otherwise distinctive American terms should be used.

I sincerely hope that you will bring some order out of what has been so confusing to both teacher and student.

S. W. WILLISTON.

CONTRIBUTION BY BAILEY WILLIS.

Your inquiries of May 5, concerning the use of certain common terms in geology and questions of classification, were duly received and have been carefully considered. In answering I beg to state that I express my personal opinion as determined by experience in practical field work and in editorial work on geologic maps.

The following answers are arranged categorically, according to the numbers of the questions to which they refer.

1. *Eras, Systems.* — Terms to be applied respectively to the grand divisions of time and the rocks representing them, as determined by the most important events of biologic development.

Periods, Groups.— Arbitrary divisions respectively of time and rocks within the eras and systems, designed to afford means of approximate designation of the position of any geologic record in the time scale. These should be applied consistently the world over according to the volume of stratigraphic evidence as checked by palæontology, but it does not necessarily follow that in North America they designate time divisions precisely contemporaneous with those distinguished in other continents.

Ages, Series. — Terms to be applied respectively to subdivisions of time and rocks less than period and group, but including a consistent sequence of biologic or lithologic changes without break. An age or series may include parts of two periods or groups.

Epochs, Formations. — Terms applied to designate the time

represented by the lithologic unit which may be mapped on a given scale and the lithologic unit itself.

Episodes for time, Lenses and Lentils or Stages for rocks.— Terms applied to local lithologic variations or limited rock masses which for purposes of discussion need to be defined, but are not of sufficient consequence to justify the distinction of a separate name.

I may briefly state my reasons for the above suggestions as follows: (1) I associate era and system because the classification is based on the broadest natural facts and is therefore systematic. (2) I associate group with period because both terms appear to me less precise and adapted to the arbitrary character of the unit thus classified. The division of time according to a scale of periods appears to me equivalent to the division of a column of mercury according to a scale of degrees to indicate temperature; whether the result be expressed in the arbitrary terms of Fahrenheit or Centigrade the fact remains unmodified. The simplest scale which will satisfy the needs of world-wide geology is to be preferred. (3) I associate age and series as both of them indicate a consistent logical sequence of events having their beginning and rounding out to an end, as in history we have the Elizabethan age and the series of events which characterize it. Age and series are natural divisions as distinguished from period and group, which are terms of the arbitrary scale. (4) I associate epoch and formation probably rather through custom than for any special reason, but I prefer epoch as a time designation to stage because the latter has a more concrete significance and might with equal aptness be applied to a subdivision of rocks. Indeed, if a geologist named to me the Medina stage, I should understand that the sandstone was referred to rather than the time for which the sandstone stands. Furthermore a stage appears to me to represent a temporary or very brief condition and to correspond in time with the term episode. The necessity for the fifth subdivision, corresponding to episode, frequently arises in detailed discussion, and is a means of avoiding complexity of nomenclature. Thus if a con-

glomerate lens appears in the Medina formation it can be referred to as the Medina conglomerate lens or episode, without burdening the discussion with a new name, which the conglomerate should receive if it be considered a formation.

2. To that extent which promotes unity of classification without contradiction of fact and no further. In case of doubt whether European standards apply to North American facts, it is better to adopt a North American standard in accordance with the facts.

3. Palæozoic era, Palæozoic system.

4. Cambrian period, Cambrian group.

5. Lower Cambrian age, Lower Cambrian series.

6. Medina epoch, Medina formation.

7. No. The multiplication of period divisions does not in my judgment tend to the advantage of geologic students.

8. The absurdity of a double meaning for any term is apparent. The usage arises from the effort at excessive subdivision in terms of periods.

9. and 10. No. This question has been several times considered, and the requirements of the case are adequately met by the use of the terms Comanche age and Comanche series.

11. Pleistocene, Neocene, Eocene.

12. I should omit Trenton and Canadian as superfluous.

13. The proposed scheme contains an undesirable number of period divisions. The sets of facts and corresponding times represented in the scheme by Pliocene, Miocene Comanche, Jurassic, Triassic, Permian, Mississippian, and Ordovician I should transfer from the list of periods to that of ages, where I think they would be adequately represented.

14. Answered under 1. BAILEY WILLIS.

CONTRIBUTION BY C. R. KEYES.

If I understand the questions rightly it would seem more logical to attempt to answer the last one first.

Uniformity of terminology is the great desideratum of working geologists. The main drawback to the adoption of any

proposed scheme appears to lie in the disinclination of most writers to make any distinction between a technical and common usage of words. Terms that already have assumed special meanings should be used only in a technical sense. For expressing ideas in which a restricted meaning is not implied there are many common terms.

In geological classification a dual scheme has come to be so universally recognized that it is difficult to imagine that any other is possible. Yet, for local successions of strata a single set of adjectives suffices to designate both the subdivisions of time and those of substance. Hence, with five orders of terms to denote the taxonomic rank of the name used—and these appear to be all that will ever be useful in practical work—we have:

Order.	For Time.	For Rocks.	Example.
1.	Era	Assemblage.	Palæozoic
2.	Period.	System.	Carboniferous.
3.	Epoch.	Series.	Mississippian.
4.	Episode.	Stage.	Kaskaskia.
5.	Hemera.	Zone.	Pentremites Godonii.

The word group, sometimes used for the largest rock division, is so thoroughly incorporated in our literature in a different sense, and is generally so loosely applied, that it seems hopeless, and in fact very undesirable, to attempt to give it, at this late day, a technical meaning. Moreover, it is far more useful now, with its present indefinite application to any selected number of beds or subdivisions, than it could possibly be in a more restricted sense. Some other title should take its place for technical purposes. It makes little difference what it is. Its general adoption is the most important feature. Assemblage, the name here given, is merely suggestive. It is somewhat ponderous, but is expressive of the grand subdivisions.

Stage is a word associated not with the idea of time, but of place. It is, therefore, more properly applicable to the fourth structural order, interchangeable, perhaps, with formation. But the latter term may be extended without confusion to crystalline

masses also. As the stages are based largely upon lithological characters and receive local geographic names, the latter are followed by such words as limestone, shale, granite, etc., thus doing away with the technical title altogether. In general the word formation seems to be best retained for use in somewhat doubtful cases, where the exact taxonomic rank is questionable, but believed to be about of the fourth order; while group refers to any of the greater orders.

The time equivalent of the stage seems best expressed by the word episode. The word Time is also appropriate, and it more exactly corresponds with the historical usage to represent a generation.

The zone is a useful subdivision of the smallest unit usually recognized in this country, The name of its time equivalent is Hemera, proposed by Buckland. The zonal classification of the Ammonite-bearing beds of the Jurassic is an example.

Assuming the ultimate aim of every scheme of geological chronology to be to provide a means of paralleling stratigraphic successions more or less widely separated geographically, a practical question arises as to how far a general classification is applicable to a given region, and how far the local plan is capable of being expanded.

While the double geological scale is theoretically everywhere balanced, in practice the time element is given precedence at the more general end of the scheme, and the rock element at the more specific or local extremity. In the present state of our knowledge general correlation farther than series is beset by many and grave difficulties, and it is doubtful whether it is feasible to extend it beyond.

So far as concerns the first two orders enumerated in the plan already given, it seems desirable, for the present, to retain the names generally applied to the different "groups," even though they are largely European in origin and are not exactly expressive of the real conditions in North America. They are so thoroughly part and parcel of our literature that it would be revolutionary to supplant them. It is better to modify their

meanings somewhat, rather than discard them altogether. Besides they have entirely lost their local original significance. They are now abstract terms. In this country the data will soon be at hand for the construction of an entirely new chronological plan, having a purely physical basis, the biological criteria being ignored altogether.

In the third order there is an overlapping of general and local criteria. To express the time factor the words Early, Mid- or Middle, and Late appear appropriate; as Early Cretaceous. The simple Anglo-Saxon names are much more preferable than the long barbarisms, produced by the Greek prefixes Eo, Meso and Neo. Simplicity of terminology should be a cardinal principle if geological science is ever to receive the popular attention it deserves. For the rock scale, Lower, Median or Middle, and Upper are useful terms to indicate in a general way the corresponding subdivisions; as Lower Cambrian, Lower Carboniferous. Or, the latter titles may be used in a somewhat indefinite way, when the exact stratigraphic limits are yet unknown.

Here the local succession begins to assume importance and the general time factor to lose it. Each geological province has its own sequence of strata. A provincial geographic name is desirable, if possible with an adjective ending. Thus, we have for the Lower Carboniferous in the Mississippi province, the Mississippian series; in the Appalachian province the Poconon series, possibly; in the Great Basin province the Aubreyan series, perhaps. The number of series is thus not fixed for any system, as locally represented, nor for different localities. Yet the epoch of all is definite. The time may come when it is desirable to have some special name to cover all the provincial series of approximately the same age, but the condition of our knowledge does not yet warrant it. It is doubtful whether it would be any improvement on the simple Lower, Middle and Upper.

An ideal feature of geological nomenclature is uniformity of endings for all terms of equal taxonomic rank. With those of the first order this method already prevails. In the case of

those of the second order a variety of different terminations exist; but it is probably not advisable now to change them. However, these names are so few in number that they are not liable to cause confusion. The provincial titles of the third order are in large part yet to be proposed. For all these an appropriate original or provincial name is suggested, with the ending *an*, if possible. This leaves the countless horde of formations, or stages, the usual units of geological mapping, the distinguishing characters of which are based chiefly upon lithology, a clear field for unchanged, local, geographic honors. The zones are named from their leading fossils.

Our information regarding the geological subdivisions is so unequally distributed that at best a very unsymmetrical classification must be endured for the present. The following seems to be the most acceptable scheme for North America:

Era.	Period.	Epoch.	
Cenozoic.	Pleistocene. Neocene. Eocene	Late or Recent. Early.	
Mesozoic.	Cretaceous. ———? ———?		
Palæozoic.	Carboniferous. Devonian. Silurian. Ordovician. Cambrian.	Late Mid. Early.	For all.
Proterozoic	Keweenawan Huronian? Laurentian? or new name.		
Azoic	Archæan.		

For purposes of instruction the provincial scheme for rocks for the special region studied may serve as a standard.

It is desirable to adhere to European standards, or the present American standards as derived from Europe, as closely as possible until our present knowledge expands sufficiently to enable us to gradually erect new and more rational standards. The first and second orders should be as closely equivalent as

possible, and with the same names for both continents, and for the whole world. It is better to have everywhere the same terminology with approximate parallelism in meaning than different names and no means of unconscious comparison.

At the present time no series are formally recognized in the Devonian. The system is doubtless as well differentiated in this respect as the Carboniferous.

It is exceedingly doubtful whether the term Permian should be permitted to hold a place in American geological literature or classification. The original Permian is perhaps applied to a provincial series, taxonomically of the same rank as Mississippian. In America the so-called Permian is also a series and actually a subdivision of the Carboniferous. The same is true of the so-called sub-Carboniferous. It follows that neither should be coördinated with the Devonian.

The use of the term sub-Carboniferous in American geology is very unfortunate. As originally proposed, and as used for a long time afterwards, it referred to an indefinite sequence of strata extending downward from the "Coal Measures" even as far as the Trenton. As more recently used the subdivision so called would be better designated the Lower Carboniferous, the serial rank being understood, Mississippian being regarded as the equivalent provincial title as explained above. Neither Carboniferous nor any other unqualified term should be used for both system and series, or any two subdivisions of different taxonomic rank.

Canadian seems wholly out of place in the sense used unless it can be modified so as to denote a series. The use of Trenton in two different senses should be discontinued. It appears unnecessary to retain the word river in connection with Hudson —even though it has been widely used. And similar double geographic names are to be avoided.

CONTRIBUTION OF SAMUEL CALVIN.

Referring to your inquiries relative to the classification of time and terranes best adapted to North American geology, I

would say that I am disposed to be very conservative and would like to see as little disturbance as possible of terms that have met with somewhat general acceptance. The terms, *Group*, *System*, *Series*, *Stage*, and the correlative time-divisions, *Era*, *Period*, *Epoch*, *Age*, are to my mind very satisfactory. Of course any other terms would answer equally well provided geologists were agreed to use them. What we need to do, as it seems to me, is to adopt in this case the method that is in most general use, and by extending the use of it to make it more and more general until it becomes universally adopted. I would not like to see the term *Formation* used in place of *Stage*, and this simply for the reason that *Formation* is now in use as a loose, general term. Such a term is very much needed, and any attempt to change *Formation* from a loose to a precise term would be attended with great confusion. Heaven knows we have confusion enough now to contend with.

It does not seem to me to do any harm to leave the Lower Carboniferous or Mississippian as a division of the Carboniferous. The use of the term Mississippian would be an advantage; and the arrangement I would prefer, simply as a result of my attitude of conservatism, would give Mississippian the same rank as Corniferous, Hamilton and Chemung in the stratigraphy of the Devonian.

The greater part of the assemblage of strata called Permian by Prosser and the geologists of Kansas University contains precisely the same fauna as our Missourian or Upper Coal Measures, and if there is no better excuse for recognizing Permian in America than that afforded by the beds in question, then America has no Permian. At all events if these strata are Permian then the Permian cannot be separated from the Carboniferous. A large percentage of the so-called Permian fauna occurs in the coal-bearing strata of Indiana, Illinois and Iowa, that is, the fauna actually begins in what we call in Iowa the Des Moines stage, or Lower Coal Measures. Personally I see no good reason for recognizing Permian in America, but if we must in order to keep up with Europe, then the Permian must rank as a subdivision of

the Carboniferous. We might therefore arrange the Carboniferous in some such way as this :

Carboniferous	Permian.	
	Pennsylvanian or Coal Measures	Missourian.
		Des Moines.
	Mississippian or Lower Carboniferous	Kaskaskia.
		Saint Louis.
		Osage or Augusta.
		Kinderhook.

9. I would prefer to leave the Cretaceous undivided, being governed in this choice simply by the conservative desire to leave things undisturbed. The literature of the Mesozoic is based on the division into the Triassic, Jurassic and Cretaceous, and any change will require a long period of adjustment and will involve endless confusion. It is much easier, and just as convenient to let the Cretaceous stand as a single system and divide it into a Lower (Comanche ?) and an Upper (unnamed) series.

Cretaceous System.	Upper Cretaceous (Black Hills series)	Denver.	
		Laramie.	
		Montana.	
		Colorado.	
		Dakota.	
	Lower Cretaceous (Comanche series)	Washita	or any other arrangement.
		Fredericksburg	
		Trinity	

The whole of the Upper Cretaceous, excepting the Laramie and Denver, is well developed around the flanks of the Black Hills.

We can retain the established names in the Cenozoic and adapt our nomenclature with perfect ease to the old arrangement

by adopting appropriate stage names. We shall here need two sets of stage names, one for the marine Tertiary and the other for the fresh-water Tertiary deposits.

Cenozoic Group........................	Pleistocene	Recent.
		Glacial.
	Tertiary	Pliocene.
		Miocene.
		Eocene.

12. There is some advantage in retaining the terms Canadian and Trenton as names of series in the Ordovician. The faunas of the Trenton limestone, the Utica and Hudson River shales are very intimately related, and that relation should be indicated by grouping the three together as stages of a single series. The Calciferous and Chazy should similarly be grouped into one series.

I believe if you have patience to read all this that you will see how I would stand with reference to the several questions in your circular letter. Any classification is arbitrary at best. A dozen or more equally good schemes might be proposed, but we should adopt and strengthen as far as possible that which is in most general use, notwithstanding the fact that it might be improved in many respects.

SAMUEL CALVIN.

PROBABLE STRATIGRAPHICAL EQUIVALENTS OF THE COAL MEASURES OF ARKANSAS.

One of the most striking features connected with the coal field of the western interior basin is the enormous thickness which the productive Coal Measures appear to attain in the southern part of the area as compared with the northern and larger portion. From the Minnesota line, southward through Iowa and Missouri, to northwestern Arkansas — a distance of more than 500 miles — the principal coal-bearing series retains a thickness of not more than 500 to 600 feet. Cretaceous and Tertiary beveling and planing, as well as later erosion, have of course thinned out the beds to a feather-edge towards the east. Passing into Arkansas the formation rapidly becomes thicker until it has a vertical measurement of more than thrice that to the north. According to Branner's[1] latest estimate the "Coal Measures" of that region are over 2400 feet thick.

In the various comments upon this great thickness which the Carboniferous rocks above the Mississippian series at once assume on passing to the south side of the Boston mountains, into the Arkansas valley, no hint has been given as to the probable conditions that produced such a remarkable phenomenon.

One thing that has tended to greatly obscure the real facts has been the assumption that the old Algonkian and old Cambrian or Silurian areas of the Ozark region formed, during all Palæozoic times, a large island in the shallow continental sea. The evidence, as recently set forth, seems indisputable that not only did no "Ozark Isle" exist during late Palæozoic time, but that the present dome-shaped, island-like character of the region, with the central old rocks, and the concentric belts of newer deposits around, was not acquired until Tertiary times. Furthermore, there is every reason to believe that the Carboniferous

[1] Am. Jour. Sci., (4), Vol. II, p. 235, 1896.

strata once extended unbrokenly over the whole area now occupied by the uplift, and that they were removed through erosion.

As already remarked the great thickening of the Coal Measures begins to make itself apparent immediately south of the Boston mountains; north of this range the stratigraphy has been more or less clearly understood. The two main subdivisions are clearly defined over all of the northern region. There they represent a lower, or coastal facies and an upper, or marine phase. The plane separating them is the base of the first thick limestone above the Mississippian series. This formation is now called the Bethany limestone. It is a marked and persistent feature of surface relief from north-central Iowa, where it emerges from beneath the Cretaceous, southward through northwestern Missouri, and southeastern Kansas, to the Indian Territory line, beyond which it has not been traced in detail, although at that point it still continues to be an important and easily recognizable ridge.[1]

Regarding the southern part of the coal field much has been written, but it has only been very lately that definite data have been given, that enables comparisons with the northern districts to be made. The facts recently published have a special importance at this time for the reason that they strongly support certain views concerning the physical conditions, the existence of which have been, for some time, suspected, and enable several statements to be formulated regarding the character of Carboniferous deposition in the region. The data particularly referred to are contained in a paper by J. P. Smith[2] on the "Marine Fossils from the Coal Measures of Arkansas." While the facts therein presented are not nearly as complete as is to be desired, they nevertheless appear sufficient, when taken in connection with information derived from other sources, to permit several pregnant deductions to be made.

One of the most noticeable features of the Carboniferous

[1] Am. Jour. Sci., (4), Vol. II, pp. 222–225, 1896.

[2] Proc. American Philos. Soc., Vol. XXXV, pp. 213–285, 1896.

deposits of Arkansas, and especially those of the western part of the state, is the prevalence of sandstones and shales above the strata of the Augusta stage (Boone chert) of the Mississippian. There are, however, in the region occupied by the Boston mountains, two limestones of unusual thickness which lie at levels considerably above the Augusta beds. These have been called[1] the Archimedes and Pentremital limestones. They are separated from each other by 40 to 75 feet of shale. The interval between the first mentioned and the limestones beneath is about 200 feet and is occupied by shales and sandstones. The Pentremital limestone may be taken, with but little doubt, as corresponding to the Kaskaskia limestone of western Illinois. Its stratigraphical, lithological and faunal characters all agree in this respect.[2] There do not appear to be any indications of a plane of unconformity at the top of this heavy Pentremital formation, as there is at the summit of an equivalent stratum along the Mississippi River. The Arkansas sequence of the Carboniferous seems unbroken and undisturbed from base to top. The Pentremital limestone may be therefore regarded as the uppermost member of the Mississippian of the region, and the overlying coal-bearing shales as the basal portion of the Coal Measures, or Des Moines series, of the more northern localities.

In regard to the upper limits of the Arkansas valley Coal Measures, or of any definitely determinable horizon in the great succession, there are not yet at hand any very critical data. The lately issued notes of Smith[3] on the fossils collected in the region by the members of the Arkansas Geological Survey give the first tangible facts that have been obtained, and by which any comparison whatever can be made with the better known region north of the Boston mountains.

All who have worked in the Arkansas valley agree in assigning a very great thickness to the Coal Measures of that region. This is readily inferred from the writings of Chance,[4]

[1] SIMONDS, Arkansas Geol. Surv., Ann. Rept. 1888, Vol. II, p. 26, 1891.

[2] American Geologist, Vol. XVI, pp. 86–91, 1895.

[3] Loc. cit.

[4] Trans. American Inst. Min. Eng., Vol. XVIII, pp. 653–661, 1890.

Winslow,[1] Stevenson,[2] Branner[3] and others. While the total thickness of the Coal Measures is doubtless somewhat overestimated by these authors, it is manifest that the formation is very thick—several times as great as it is farther northward.

The subdivisions of the Arkansas Coal Measures that have been recognized have not always been the same. In several instances they have been quite different. The classifications have been either noncommittal as to exact correlation with other regions, or they have been very general. The members distinguished have been largely for convenience in local field work. The tendency has been, however, to regard the Coal Measures of this region as about equivalent to the Coal Measures ("upper and lower divisions") of other districts north and east, with the intimation, in the later notes, that the so-called Permian of the western part of the Mississippi basin, may be present to some extent, as for example on Poteau mountain. In the latest contribution to the subject by Smith,[4] the "Upper Coal Measures" and the "Lower Coal Measures" of the Arkansas valley are paralleled with the similarly named formations of the Missouri region. The Poteau mountain beds are included. The conclusion is that "there is not sufficient reason for classing the Poteau mountain beds with the Permian, but their fauna, as well as stratigraphic position, place them very high in the Coal Measures, since they are like the fauna and position of the Mississippi valley Upper Coal Measures. These beds derive an additional interest from the fact that on Poteau mountain 1000 feet of shale, in which no fossils were sought for, lie above the thin layer from which the entire collection was taken; thus the chance of finding true Permian beds in that region are very good." From this it will be seen at once that the Arkansas section is regarded as representing the Des Moines and Missourian series of Missouri and Kansas, as embraced between the Mississippian limestones

[1] Bull. Geol. Soc. America, Vol. II, pp. 225-242, 1891.

[2] Trans. New York Acad. Sci., Vol. XV, pp. 50–61, 1895.

[3] Am. Jour. Sci., (4), Vol. II, p. 235, 1896.

[4] Loc. cit.

and the Cottonwood limestone of the central part of the last mentioned state.

A careful comparison of the species of fossils that are considered by Smith from the "Upper Coal Measures" with those from the Upper and Lower Coal Measures of other parts of the Western Interior basin brings out the fact that the Arkansas fauna not only does not necessarily indicate a "very high" position in the Upper Coal Measures of the zone containing it, but that it may be, and probably is, very low. Judging from the fauna alone, and as a whole, according to the palæontological standard of its nearest and most closely related districts—the Missouri-Kansas province, with which it is properly compared—the indications are that the age of the strata yielding it is not that of the "Upper Coal Measures" at all, but of the "lower division"—that is, of the Des Moines series of the more northern localities.

All of the Arkansas species, with very few exceptions, are, in Iowa, Missouri and Kansas, the most widely distributed forms. Most of them range from the base to the top of the Des Moines series, and continue on upwards. In the lower series the marine beds are almost wholly absent, only a few thin limestones being present in the whole succession. Nevertheless the same species that are found in Arkansas occur abundantly not only in the thin limestone layers, which are rarely more than a few inches in thickness, but also in the calcareous shales, and, in less numbers even in the bituminous shales.

Of the corals listed from Arkansas only one form has a range that is unusually "high" in the northern succession; all of the others start almost from the very base of the series. The crinoids and bryozoans are all common in the Lower Coal Measures. All fourteen species of brachiopods are of very frequent occurence in the lower coal division, many commencing down in the Mississippian. One possible exception is *Terebratula bovidens*, which at present appears to be absent from some of the lower Des Moines beds. Of the lamellibranchs, all twenty-two species are the most characteristic forms of the very base

of the Missourian; one-half of the number are found lower down, and no less than seven are typical Des Moines forms, in fact having an *optimum habitat* not in the marine beds but in the bituminous shales. The seven species of glossophora that are enumerated are the most abundant forms of the Lower Coal Measures throughout the northern district, and they are pre-eminently the characteristic fossils of the black shales everywhere. Among the ten cephalopods named, no less than five are of common occurrence in the Des Moines beds, and not infrequently they are found in the black shales; the other five, so far as known, range low in the Missourian.

If the faunal evidence, as recently presented, is to be relied upon at all, it would appear that there are no grounds for believing that there are necessarily present in the deposits of the Arkansas valley region any strata higher than the base of the Missourian series of Missouri and Kansas.

There is, however, another reason for believing that no part of the Missourian series, or its equivalent, exists in Arkansas. The general stratigraphy as far as it is now understood, gives not only no indication of the Missourian beds being represented in the region, but points almost conclusively to their absence.

The broad belt of lowland, lying below the contour of 1000 feet, and between the Ozark uplift and the elevated region of the Great Plains, extends from the Missouri river southwestwardly into Indian Territory and then eastwardly through the Arkansas valley to the savannas of the Mississippi embayment. This lowland is occupied chiefly by shales which have relatively much less resistant powers to erosion than the limestones on either side of the belt. In Missouri the subdivisions of the Coal Measures, both "Upper" and "Lower," have been clearly made out. In Kansas Haworth[1] has traced the same divisions to the Indian Territory line, so that down to the juncture of the great lowland valley and that of the Arkansas, the surface distribution of the several formations of

[1] Univ. Geol. Surv. Kansas, Vol. I, 1896.

the Carboniferous is well known. In Indian Territory the information is not yet as full as would be desirable. Still there are enough facts at hand to indicate the general features of the main subdivisions, or series. The Missourian, or more strictly marine series, composed of important limestones, does not appear to extend down the Arkansas valley into Arkansas, nor to change very much in lithological character. The Pawhuski limestone in eastern Oklahoma, regarded by Smith[1] as representing the same horizon of "Upper Coal Measures" farther east, certainly cannot be stratigraphically equivalent to any part of the Coal Measures that exist in the same latitude in Indian Territory. While it is not yet known with certainty just what its exact equivalent is, it is quite probable that it is the southern extension of what is termed the Iola limestone in the region to the north. If this is the case, the position of the limestone exposed in the quarries at Pawhuski is very near the base of the Missourian, or "Upper Coal Measures."

If, as now appears probable, the enormously thick Coal Measures of the Arkansas valley are practically the exact equivalents of only the lower division, or the Des Moines series of the region farther north, instead of representing the entire interval between the Mississippian and the so-called Permian (Oklahoman), or that part of the Carboniferous above the Cottonwood limestone in Kansas and Oklahoma, the explanation of the great increase in the thickness southward, would seem still more difficult. There have been, however, a number of new facts recently brought out regarding the diastatic changes that have taken place in the Ozark region, and some of these have a direct bearing upon the question under consideration.

It has been lately shown[2] that during the Kaskaskia, or closing epoch of early Carboniferous times in the Mississippi valley, there was a series of rapid changes in the relations of land and sea. At the beginning of the Kaskaskia the shore line had moved southward 400 to 500 miles at least from the

[1] Proc. Amer. Philos. Soc., Vol. XXXV, p. 230, 1896.

[2] Bull. Geol. Soc. America, Vol. III, p. 296, 1892.

latitude it occupied during the St. Louis, or approximately to the latitude of the present mouth of the Missouri River. This permitted erosion of the land surface north of this point; and immediately south of it the disposition of coarse sediments, covering the other marine beds of the Mississippian. Marine deposits of the later Kaskaskia, were again laid down over the coastal deposits of the same region. With a further recession of the sea some of the territory occupied by Kaskaskia rocks was also made land and was subjected to erosion. According to the recent suggestions of Marbut[1] the shore line at this time, when it had traveled farthest to the southward, coincided very nearly with the present crest of the Ozark uplift, that extends along a line drawn from Iron Mountain to the southwest corner of the state of Missouri.

It is now a well-established fact that everywhere to the north of the present Ozark crest profound erosion took place between the time when the St. Louis limestone was deposited and that when the Coal Measures were formed. Moreover, the effect of this land degradation must have left the country very much in the condition of a peneplane, for the old land surface is a rather even one, with no marked contrasts of relief. It beveled the previously slightly tilted strata, for the Coal Measures rest on the rocks of all ages from the Silurian to the top of the Lower Carboniferous. This stratigraphic hiatus, represented by the plane of unconformity at the base of the northern Coal Measures, manifestly indicates an episode in the physical history of the region, the importance of which has been heretofore little appreciated.

In the southerly retreat of the sea during the close of Lower Carboniferous time, there was, of course, a point beyond which the shore line did not advance. Beyond this point, seawardly, deposition went on uninterruptedly, the succession of beds was continuous, and the layers were conformable throughout the Carboniferous system. Such conditions appear to have prevailed in the region of southern Missouri and northern

[1] Missouri Geol. Surv., Vol. X, p. 82, 1896.

Arkansas. South of the Ozark crest, if the inferences already drawn are to be relied upon, deposition was continuous, not only through the Lower Carboniferous period, but also during the

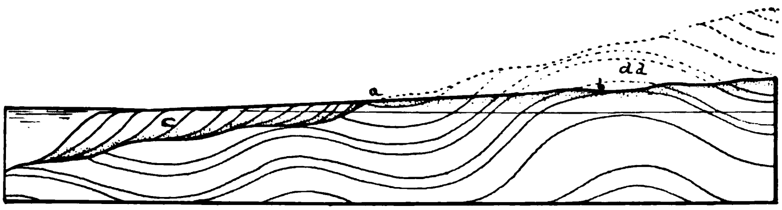

FIG. 1.—Ideal Conditions of Sedimentation.

interval when the region farther north was a land surface being rapidly eroded. As shown elsewhere,[1] the present Ozark dome had, of course, not begun to bow up. It was not a large island during the Carboniferous, as has been generally regarded. The

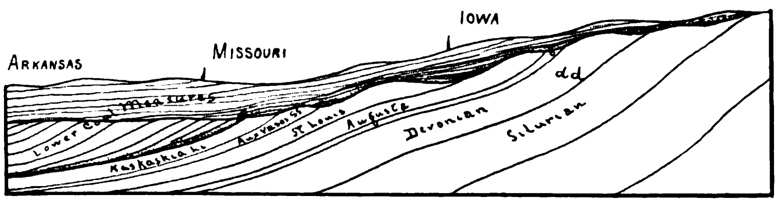

FIG. 2.—Cross Section of Mississippi Basin—Minnesota to Arkansas.

products of land degradation were, without doubt, dumped into the adjoining seas, just as the sediments of the present continent are being carried into the ocean to form the thick fringe of coarse shore deposits.

In general, the deposition of coarse sediments along the coast must have been represented by degradation on land. This phenomenon may be shown by the subjoined sketch (Fig. 1), in which *a* is the original shore line; *b*, the land surface; *c*, the sediments removed and transported from the eroded parts of the strata *d*, *d*, which had been subjected to deformation since their formation. Identically the same conditions obtained in the case

[1] Missouri Geol. Surv., Vol. VIII, p. 352, 1895.

of the Carboniferous deposits of the Continental Interior. It is also representative of the conditions existing at the present day on the Gulf coast, and is typical of sedimentation generally.

A diagrammatic cross-section, north and south, from Minnesota to central Arkansas, and representing the relations of the Carboniferous deposits of the region, is given in Fig. 2.

The true marine beds of the Missourian series, or "Upper Coal Measures," may have extended, and probably did stretch out over a considerable part, and possibly all, of the region; but erosion, since Carboniferous times, has removed all traces of these deposits.

CHARLES R. KEYES.

ON THE ORIGIN OF CERTAIN SILICEOUS ROCKS.

I. NOTES ON ARKANSAS NOVACULITE.

An examination of the residues of specimens representing both the Ouachita and Arkansas (commercial) types of novaculite confirms Griswold's observations and conclusions made on thin sections. Ground in an agate or porcelain mortar, the greater part of the rock is easily reduced to a fine slime that readily floats away in water. A considerable portion, however, consists of granules which, though made up of fine grains, require considerable rubbing to reduce them to slime. Even when, in the final stages of the grinding, a soft pestle is employed to avoid breaking up the grains of quartz and other minerals, a considerable number of the aggregated granules remain, thus showing a strong cohesion of the constituent grains.

The amount of quartz in simple grains that can be positively identified by the polarization colors is not large, and for the most part is not distinctly detrital. Such grains are frequently enclosed in the composite ones or have composite silica adhering to them, and often appear to be more completely developed individuals of the aggregated grains. In many cases, however, they appear to be detrital grains with adherent secondary silica. Unmistakable detrital grains are represented by numerous zircons and rare fragments of tourmaline and garnet.[1] These are exceedingly fine, and both in character and amount seem to confirm Griswold's conclusion that the deposit took place in still and comparatively deep water into which only a small amount of very fine detritus would be floated.

The great bulk of the silica of these rocks appears to be secondary, and to account for its peculiarities the replacement hypothesis of Rutley seems to offer less difficulty than that of

[1] Wichmann found garnets in the novaculites of the Marquette, Mich., district in 1879. Q. J. Geol Soc., Vol. XXXV, 1879, pp. 156–164, J. C. Branner.

an originally siliceous sediment of Griswold. The latter must either have been chemical, which Griswold expressly rejects, and apparently very properly, or composed of very fine granular quartz. In the latter case the granules, however fine, have been still further granulated, a species of metamorphism which has apparently not been observed elsewhere, and which is difficult to conceive. The metamorphism, if there had been any, would rather be expected to be in the direction of larger and well-defined grains of quartz, such as were noted in some of Griswold's slides (No. 14).[1] The latter slide seems to be a case of replacement according to Rutley's hypothesis "caught in the act." It may be suspected that in a larger suite, especially of non-commercial stones, other such cases might be found.

Griswold's explanation of the cavities seems also to point in the direction of a replacement, and can be reconciled with Rutley's hypothesis on the supposition, which does not seem difficult, that part of the original calcareous sediment may have crystallized (not necessarily as dolomite) and thus have offered greater resistance to the replacement.

The description of the beds also is suggestive of original limestones with cherty layers and nodules. Two of the specimens sent appear to me to represent such cherts, though I should not call them metamorphosed.

The question of the state of the silica seems to me to be one of quite secondary importance, as in the case of silicified wood replacement silica is met with in all states, and often with an appearance of a passage to the state of quartz after the replacement.

Viewing the question from a distance, and on a very insufficient basis, it seems probable that if Mr. Griswold had taken into consideration the hypothesis of a replacement of calcareous sediments, he would, perhaps, have found much more in its favor than either Rutley or I could see.

For the study of crucial points, "non-commercial" rock will

[1] Whetstones and the Novaculites of Arkansas. By L. S. GRISWOLD. Ann. Rep. Geol. Surv. Ark. for 1890, III, p. 128.

probably be often better than the "commercial," and the preparation and examination of residues more rapid and satisfactory than that of microscopic sections.

ORVILLE A. DERBY.

SÃO PAULO, Brazil, April 6, 1898.

II. ON THE ORIGIN OF NOVACULITES AND RELATED ROCKS.

The preceding part of this paper was recently received by me from Professor O. A. Derby as embodying the results of his examination of novaculites by a method hitherto not employed with those rocks. It should be added that in a former letter he sent me the results of a study by this same method of an impure cherty Carboniferous limestone from Tietê, São Paulo. In this limestone he found by crushing and washing, rolled quartz, zircon, rutile, garnet, tourmaline, etc.

These notes I have taken the liberty to publish without consulting Professor Derby in order that the results of his work may become available for others who may study this interesting and important group of rocks.

It is remarkable that so many different views have been held regarding the origin of novaculites and of the closely related highly siliceous rocks known as jaspilites and sometimes as jaspers, siliceous shales, etc.

The following theories have been advanced to explain the origin of these rocks:

Foster and Whitney seem to have regarded the jaspers of Michigan[1] as segregations of eruptive origin. Owen considered the Arkansas novaculites as metamorphosed sandstone.[2]

Kimball believed the Marquette iron ores and their associated jaspers to be metamorphic rocks of sedimentary origin, presumably mechanical.[3]

[1] Geology and Topography of the Lake Superior Land District. Pt. II. The Iron Region, pp. 67–69, 1851.

[2] Second Geol. Surv. Ark., pp. 23, 25, 1860.

[3] Am. Jour. Sci., Vol. XXXIX, p. 303, 1865.

Crosby thinks some of the jaspers and quartzites are the siliceous oozes of the deep sea, that is, that they are of organic origin.[1]

Wadsworth at first believed in an eruptive origin for the jaspilites.[2] This view he modified later.

Julien believes in the mechanical sedimentary origin of the jasper iron ores of the Marquette region, and it is to be presumed that he considers the jaspers mechanical sediments also.[3]

Irving concluded that the jaspers were formed by silica replacing dolomite or calcite.[4]

Reyer thinks the sediments associated with the iron ores of Michigan are derived partly from decomposed igneous rocks and partly from organic remains.[5]

Branner has suggested that the compact novaculites may be metamorphosed cherts.[6]

Comstock considered many of the Arkansas novaculites to be hot water deposits.[7]

Julien thinks amorphous silica is produced by marine organisms, or by precipitation from solutions.[8]

Griswold is of the opinion that novaculites are simply metamorphosed, fine grained, mechanical sediments.[9]

N. H. and H. V. Winchell believe in the theory of chemical precipitation for the jaspilites.[10]

James E. Mills is of the opinion that certain quartzites of the

[1] Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 167–168, 1878–1880.

[2] Bull. Mus. Comp. Zool., Vol. VII, p. 30, 1880; Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 477–478, 1878–1880; Bull. Mus. Comp. Zool. Harvard Col., Geol. Ser. I, Vol. XVI, pp. 331–565, 1884.

[3] Genesis of the Crystalline Iron Ores. By A. A. JULIEN. Eng. Mining Jour., Vol. XXVII, pp. 81–83, 1884.

[4] Am. Jour. Sci., Vol. XXXII, p. 255, 1886.

[5] Geologie der amerikanischen Eisenlagerstätten. E. REYER. Oest. Zeitsch. f. Berg. u. Huttenwesen, XXXV, Nos. 10 and 11, 1887.

[6] Ann. Rep. Geol. Surv. Ark., Vol. I, p. 49, footnote, 1888.

[7] Ann. Rep. Geol. Surv. Ark., Vol. I, pp. 95. 129, 1888.

[8] Proc. A. A. A. S., Vol. XXVII, pp. 311–340, 1889.

[9] Ann. Rep. Geol. Surv. Ark., Vol. III, pp. 164, 194, 1890.

[10] The Iron Ores of Minnesota. By N. H. and H. V. WINCHELL. Minneapolis, 1891, p. 74.

Sierras, in California, are replacements of clays by silica,[1] and that others are possibly replacements of limestone by silica.

Wadsworth came to believe in their sedimentary origin.[2]

Rutley in a review of the subject reached the conclusion that the novaculites were replacements by silica of dolomites or of dolomitic limestones.[3]

Hinde expressed the opinion on the occasion of the reading of Rutley's paper that these rocks were of organic origin.[4]

Lawson thinks the "radiolarian cherts," that is, the jaspers of the coast ranges of California, are local deposits chemically precipitated from submarine siliceous springs.[5]

Branner thinks the jaspers are of organic origin.[6]

Van Hise in speaking of certain jaspers of the Marquette district says: "It appears highly probable that dynamic action transformed the ferruginous chert into the jasper."[7]

Derby's views, that novaculites are replacements of limestones by silica, are given in the first part of the present paper.

Fairbanks has concluded that the Tertiary siliceous shales of the coast ranges of California are derived from diatomaceous beds.[8]

Doubtless many other expressions of views regarding the origin of these siliceous rocks might readily be found, but these are enough to show that there has been the widest possible difference of opinions on the subject.

We have then the following theories, that the novaculites, jaspilites, jaspers, etc., are:

1. Mechanical silts.
2. Organic silts.

[1] Bull. Geol. Soc. Am., Vol. III, pp. 421–422, 440, 1892.

[2] M. E. Wadsworth, Rep. State Geol. for 1891–2. State Board of Geol. Surv. (of Michigan) for 1891–2. Lansing, 1893, pp. 75–155, dated March 1892.

[3] Quart. Jour. Geol. Soc., Vol. L, p. 386, 1894.

[4] Quart. Jour. Geol. Soc., Vol. L, p. 391–392, 1894.

[5] 15th Ann. Rep. U. S. G. S., pp. 425–426, 1895.

[6] Trans. Amer. Soc. C. E., Vol. XXXIX, p. 58. Read Nov. 17, 1897.

[7] Monog. U. S. G. S., Vol. XXVIII, p. 372, 1897.

[8] San Luis Obispo folio, U. S. G. S. (MSS.).

3. Chemical precipitates.
4. Igneous deposits.
5. Replacements of clays.
6. Replacements of limestones.
7. Replacements of dolomites.

The most comprehensive discussions of this subject are those of Griswold and of Rutley. But these writers do not agree in regard to the origin of the rocks, the former believing them to be fine sediments, the latter believing them to be replacements of dolomites or limestones.

My own opinions have not been based upon such microscopic study as either Griswold or Rutley devoted to this work, and for that reason were not worthy of special consideration. Since I began to study the geology of the coast ranges of California, however, I have, I believe, seen much that throws light upon the origin of the novaculites and similar rocks.

These observations embrace those upon geological structure, gross and microscopic structure, composition and geological relations, and lead me to believe that the white siliceous shales so characteristic of the Tertiary, the jaspers and the diatomaceous beds are only various phases of the same thing.

I am glad to say that Dr. H. W. Fairbanks, whose acquaintance with the coast range geology makes his opinion especially valuable, expresses similar views on this subject. Dr. Fairbanks, however, has undertaken a thorough study of this subject from which important results may be expected.

J. C. Branner.

Stanford University, California.
June 4, 1898.

A STUDY OF SOME EXAMPLES OF ROCK VARIATION.[1]

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IN the following article I purpose to describe briefly a series of igneous rocks which vary from those of acid character through those of intermediate and basic characters to others which are ultrabasic in composition. The rocks occur upon the upper peninsula of Michigan, in the vicinity of Crystal Falls, the most important town in the iron-bearing district of the same name. All are to be found in an area extending from Crystal Falls southeast to a mile east of the Michigamme River. In the description of the various kinds no detailed mention of localities will be given, since they are given in the complete article, and if wanted can readily be found by reference to it. The rocks occur as knobs or groups of knobs, and as well determinable dikes cutting the knobs. The outcrops project through an area covered by glacial deposits. The best exposures are naturally near the river, where erosion has removed the drift mantle.

Here and there in the drift are isolated exposures of sedimentary rocks of Upper Huronian age. The relations of the igneous rocks to the sedimentaries are not shown by exposures of direct contacts, but it is inferred from the occurrence of sedimentaries between the igneous exposures that the drift is underlain by Upper Huronian sedimentaries, and that the igneous rocks are intrusive in them. The intrusives have never been found to penetrate the superimposed, horizontal, Lake Superior, Potsdam sandstone. These facts are conclusive proof that their period of

[1] This article is a brief abstract of a part of a report which will appear in full as a monograph of the U. S. Geol. Surv., under the title of "The Crystal Falls Iron-bearing District of Michigan." For details which are not warranted in this place the reader is referred to the monograph. An abstract of the monograph, in which the portion treated in the present article is barely mentioned on account of lack of space, will be published under the same title as the monograph in the 19th Annual Report.

intrusion fell in the time between the deposits of the Upper Huronian and those of the Cambrian. In the complete article there is a discussion of the time of the folding of the Upper Huronian, and the conclusion is reached that this folding took place immediately preceding the deposit of the Keweenawan series. If these intrusives had existed at that time, they must certainly have suffered from the orogenic movements. Examination of the exposures of the intrusives has not shown schistose masses, nor has detailed microscopical study disclosed any textures which accompany powerful dynamic movements, except in isolated cases which are presumed to be due to purely local movements. Such being the case, the conclusion follows that these intrusives are subsequent in their origin to the folding of the Upper Huronian; that is, are of Keweenawan or of post-Keweenawan age.

It seems highly probable, though it cannot now be proven, that the intrusives are contemporaneous with the period of volcanic activity, during which the heterogenous Keweenawan series was formed. During the formation of such a great series we might well expect more or less fissuring of the sedimentaries and intrusion of molten magma in a district no farther removed from the scene of eruptive activity than is the Crystal Falls district from the Keweenawan, a distance of about thirty miles. It is at least clear that the rocks are post-Huronian and pre-Potsdam, but a closer approximation cannot be made with certainty.

With few exceptions the intrusive rocks are medium to coarse-grained. While the granitic texture is unquestionably predominant, other textures are not absent, for we find some ophitic and porphyritic textured rocks, and others in which even a parallel (flow) texture has been produced. It has already been intimated that the chemical range is very great. There is, of course, a corresponding range in color.

The main classes with which the variations will be grouped are the diorites, the gabbros, or gabbro-norites, and the peridotites. Complete and accurate chemical analyses of certain

rocks of these chief classes have been obtained and the microscopical diagnosis thereby confirmed. Within each of these main divisions well marked varieties can be distinguished. While between the gabbros and the peridotites a transition is unquestionable, a less positive statement must be made for the connection between the diorites and the gabbros, and while the writer is convinced that such connection exists, he is aware that the reader may not take the same position. In the following pages the three main classes will be briefly described, and then the variations within each class. The relations between the various main divisions will be described, and then, with a brief summary of the facts, the reader will be enabled to draw his own conclusions.

Diorites.—Following Brögger's definition,[1] the name diorite is in the following pages restricted to granitic textured plutonic rocks of intermediate acidity, consisting essentially of plagioclase and either primary hornblende, pyroxene, or mica, or two or more of these.

This is very different from the usage by a number of the previous writers on the Lake Superior region, who called the uralitized dolerites "diorites" or "epidiorites." As a result of the introduction of the use of this name diorite by scientific men, it is now in common use among the miners in the Lake Superior iron regions, and is usually applied by them to any greenish rock whose sedimentary characters are not clearly recognized, very much in the same way that the field geologist uses greenstone, especially if the green rock is associated with an iron formation. In the great majority of cases such rocks are dolerites in a more or less advanced stage of alteration, and rarely, if at all, pure diorites.

The dioritic rocks are of medium to coarse grain. In texture they show some variations from rocks of a granitic texture

[1] Die Eruptivgesteine des Kristianiagebietes, by W. C. Brögger in Videnskabsselskabets Skrifter, I Mathematisk- naturv. Klasse. Pt. I, Die Gesteine der Grorudit-Tinguait-Serie, 1894, No. 4, p. 93. Pt. II, Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, 1895, No. 7, p. 35.

to others which incline to the ophitic texture, and to still others which are distinctly micropegmatitic. The granitic texture is the most frequent. The color is uniformly light gray or reddish, but at times, when the ferromagnesian minerals are present in greater quantity, they become dark gray or greenish brown.

The important mineral constituents are feldspar, quartz, hornblende, and biotite. Apatite, zircon, sphene, iron oxide, and epidote (?) are the accessory minerals. The secondary minerals present are white and brown mica, chlorite, epidote, zoisite, calcite, and rutile. Plagioclase feldspar, orthoclase, and microcline occur together. The plagioclase is present in individuals which are fairly automorphic. In the ophitic textured diorites, the plagioclase is the best developed of any of the essential constituents. In the granitic textured rocks the degree of automorphism is highest where orthoclase and quartz are present in the largest quantity, and diminish as these diminish in consequence of the interference of the plagioclase individuals. For the most part the plagioclases yield rather narrow sections, though they can hardly be called lath-shaped. Measurements show the plagioclase to be andesine. It is very much altered. Orthoclase is present in large plates, which form a part of the mesostasis for the plagioclase and the bisilicates. The quantity of orthoclase varies considerably. It is very much decomposed. Microcline is not abundant. It is very fresh, and in many cases automorphic with respect to the orthoclase and quartz. Quartz is present in variable quantity, and with the orthoclase forms the mesostasis. The hornblende shows a good development in the prismatic zone. The terminal planes are not so well developed. It varies from dirty green to reddish-brown in color. The reddish-brown variety occurs in the center of the crystals and is surrounded by the green. The differently colored zones thus produced are not sharply delimited, and are also in perfect optical continuity. No evidence is found indicating the green kind to be an alteration product from the brown variety, and they are both assumed to be primary. The biotite is brown,

and shows its usual characters. It is less well developed than the hornblende. All of the other minerals show their usual well-known characters.

According to the variations in the proportions of the essential minerals, plagioclase, orthoclase, quartz, hornblende, and biotite, we get the following varieties of diorite: quartz-diorite, tonalite, quartz-mica-diorite, and mica-diorite. This variation is best shown in a connected group of knobs composed of medium grained rock, which varies in color from light pink to a very dark greenish-gray. Areas of light and dark colored rock may be seen extending in finger-like projections into one another. There are no sharp boundaries between them, however, but, on the contrary, a gradual passage from the light to the dark variety. Some of the rocks also contain small, more or less rounded areas, which are clearly segregations of ferro-magnesian minerals. These different phases evidently belong to a single rock mass, but the microscope enables a separation to be made into the several mineralogical and textural facies already mentioned. The main mass of the rock forming the knobs appears to be a tonalite which resembles the published description by Becke[1] of that from the Rieserferner. It also closely resembles some slides of the typical Adamello tonalite with which I have been able to compare it. This tonalite grades by diminution of biotite with corresponding increase of hornblende into quartz-diorite, and by a diminution or disappearance of the hornblende and increase of the biotite into a quartz-mica-diorite. Where the quartz of this last variety is practically wanting, we get a mica-diorite. In this small massif pure types of the rocks described are of rare occurrence. Orthoclase is present in all of these dioritic rocks. In certain facies the orthoclase and quartz are very abundant, and the plagioclase correspondingly subordinate. Such rocks approach closely the plagioclase-bearing granites.

The relationship to granites is better shown in a different

[1] Petrographische Studien am Tonalit der Rieserferner, by F. BECKE, Tsch. Mitt. Vol. XIII, 1892, pp. 379–464.

occurrence from the one just described, in which the greater portion of the rock is a plagioclase-bearing biotite-granite, showing in many cases most beautiful micropegmatitic texture, but with schlieren of a darker colored rock which might readily be called a quartz-mica-diorite. It is especially interesting to note also that this series of exposures is cut by a number of small dikes of uniform character, varying from fractions of an inch to three inches in width. The dike rock is very light gray to pink in color, and cryptocrystalline. Examined under the microscope, these dikes can be readily separated into a microporphyritic center, and a microgranitic textured selvage. Phenocrysts of quartz, feldspar, and biotite lie in a microgranitic groundmass of feldspar and quartz, between which occur secondary flakes of muscovite. The rock is a microporphyritic quartz-mica-diorite or quartz-mica-diorite-porphyry. This rock seems to bear a very strong resemblance to the tonalite-porphyrite described by Becke[1] which occurs as a dike facies of the Rieserferner tonalite to which I have already referred.

Still another illustration of the passage from the granitic to the dioritic rocks was observed upon a dike, four feet wide, which penetrates a knob of hornblende-gabbro. A specimen taken near the center of the dike discloses itself as a biotite-granite with a small amount of plagioclase. The sides of the dike consist of diorite, composed of andesine feldspar, and biotite, without any quartz. The sharp line of demarkation which exists between the dike and the gabbro seems to preclude the possibility of a fusion and mingling of the two rocks, such as has been suggested by Johnston-Lavis,[2] as in some cases causing variation in chemical composition of intrusive rocks, especially where this variation is one between the center and periphery of an intrusive mass. The diorite occurrences of the Crystal Falls district seem, in the gradations mentioned, to

[1] Loc. cit., pp. 434–441.

[2] The causes of variation in the composition of igneous rocks, by H. J. JOHNSTON-LAVIS: Natural Science, No. 4, pp. 134–146.

The basic eruptive rocks of Gran, Norway, and their interpretation, by H. J. JOHNSTON-LAVIS: Geol. Mag., 4th decade, Vol. I, 1894, p. 252.

be very similar to the tonalite from the Rieserferner described by Becke,[1] and also to the so-called grano-diorite massifs of California, described by Becker, Turner,[2] and Lindgren.[3] The grano-diorite of California appears from Lindgren's description to correspond very closely to tonalite, though Turner uses the name as synonymous with quartz-mica-diorite.

It has not been found possible thus far to obtain analyses of all these varieties. The more acid facies of the diorites seem to show very clearly their gradation towards tonalites and granites, and, from their content of free silica, the conclusion seems to be warranted that they are rather acid. Such being the case, it was deemed of more importance to study the relations of the less acid dioritic facies in order to determine their relationship with the basic gabbros and peridotites with which their connection is not so evident as it is with the granites. To this end a complete analysis was made by Dr. H. N. Stokes of a mica-diorite. The rock analyzed consists of biotite, hornblende, plagioclase, orthoclase, and quartz, with the biotite and plagioclase as the predominant characteristic constituents.

ANALYSIS OF MICA-DIORITE BY DR. N. H. STOKES.

SiO_2	58.51	MgO	3.73
TiO_2	.72	K_2O	4.08
Al_2O_3	16.32	Na_2O	3.11
Cr_2O_3	none	H_2O at 110°	.23
Fe_2O_3	2.11	H_2O above 110°	2.00
FeO	4.43	P_2O_5	.30
MnO	trace	CO_2	none
NiO	none		
CaO	3.92		99.46

Gabbros and norites.—The gabbros and norites are holocrystalline rocks of moderately fine to coarse grain. The rocks here included show a considerable variation in texture. Some

[1] Op. cit.

[2] Geology of the Sierra Nevada, by H. W. TURNER: 17th Ann. Rep. U. S. Geol. Surv., No. 1, 1896, pp. 636–724.

[3] Granitic rocks of California, by W. LINDGREN: Am. Jour. Sci., 4th series, Vol. III, 1897, p. 308. Here can be found reference to earlier articles on grano-diorites.

of the finest grained forms possess a very good parallel texture. Others are noticeably porphyritic. A few have a poikilitic texture. Less common is an approach to the ophitic texture of the dolerites. Most commonly of all, however, the rocks are granitic in texture. The color variation is not great, and is chiefly in dark brown or greenish-black tones. The important mineral constituents are feldspar, biotite, hornblende, pyroxene, and olivine. Apatite, sphene, zircon, rutile, octahedrite, brookite (?), and iron oxide occur as accessory minerals. White and brown mica, chlorite, hornblende, talc, serpentine, sphene, rutile, and calcite occur as secondary minerals.

Plagioclase and orthoclase-feldspar are both present. The last is, however, of doubtful occurrence. The plagioclase is labradorite, and shows its usual characters.

Hornblende is the most striking component in the majority of the sections. It is present in three different varieties, all of which occur in anhedra. The most prominent kind is a reddish-brown hornblende, which has a dark green hornblende commonly associated with it, and frequently in zonal intergrowth with it. This hornblende occurs without the green kind, but the green is invariably associated with the brown variety. The two are optically continuous in the intergrowth. It is possible, though not susceptible of proof, in the sections examined, that the green hornblende is the incipient alteration of the brown hornblende. The pleochroism is strong in the following colors:

Brown hornblende.

a	**b**	**c**
Light yellow or red, with tinge of green.	Reddish-brown.	Same as **b**, or else a darker reddish-brown. Exceptionally it is a light yellowish-brown.

c > **b** >> **a**

Green hornblende.

a	**b**	**c**
Greenish-yellow.	Yellowish or brownish-green.	Darker olive-green. Frequently with bluish tinge.

c > **b** > **a**

This hornblende, with respect to its rather exceptional pleochroism and its general characters, seems to agree very well with that described by van Horn[1] from very similar rocks from Italy, and like that is possibly very basic. The brown hornblende possesses a further interest in that it is frequently rendered very dark by the number of exceedingly small inclusions within it, and in this, and also in its color, resembles so strongly hypersthene as to be readily mistaken for it upon cursory examination. The inclusions referred to are determined to consist of characteristic heart-shaped and geniculate twins of rutile, and pointed pyramidal crystals of octahedrite. Others show a flat tabular development, somewhat similar to that of brookite, though these could not be positively determined as that mineral. Associated with the above were numbers of hexagonal, clove-brown plates appearing in cross section as sharp lines. A gradation between these plates and large masses of ilmenite was traced. It thus appears that these inclusions are all titaniferous minerals.

The second kind of hornblende is the compact, strongly pleochroic common green hornblende, and the third kind is a non-compact reedy variety of light green hornblende. This last is probably secondary, but secondary after the original hornblende, thus not affecting essentially the character of the rock.

The pyroxene is represented by a monoclinic variety and by the orthorhombic bronzite. The presence of olivine was determined with considerable doubt. None of the remaining minerals show anything of special interest.

The leading essential constituents described are combined in variable quantities, and accordingly a number of different mineralogical types of rocks are produced. The important types which will be described are hornblende-gabbro, consisting essentially of hornblende and labradorite; gabbro, consisting of monoclinic pyroxene and labradorite; and bronzite-norite, com-

[1] Petrographische Untersuchungen über die Noritischen Gesteine der Umgegend von Ivrea in Oberitalien, by F. R. VAN HORN. Tsch. Mitt., V Heft, 17 Bd., 1897, p. 409.

posed of bronzite and labradorite. These various mineralogical types exhibit very interesting ranges in texture, to which attention will be called. The hornblende-gabbro of granitic texture is the prevailing rock. An analysis of such a rock shows the following composition:

ANALYSIS OF HORNBLENDE-GABBRO BY MR. GEORGE STEIGER.

SiO_2	49.80	Na_2O	2.22
TiO_2	.79	H_2O 100°−	.13
Al_2O_3	19.96	H_2O 100°+	1.71
Fe_2O_3	6.32	P_2O_5	.07
FeO	.49	CO_2	.15
CaO	11.33		
MgO	7.05		100.63
K_2O	.61		

In one of the hornblende gabbros a porphyritic texture is very pronounced. Porphyritic brown hornblendes, which are poikilitic from inclusions of feldspar and a few grains of augite, lie in an imperfectly ophitic groundmass. This rock grades into a finer grained nonporphyritic granitic textured gabbro. Both mineralogical and textural variations are well shown in another occurrence, in which the relations of the respective varieties are clearly seen. The normal granitic hornblende-gabbro is cut by numerous narrow bifurcating dikes, which are very dark, of fine grain, and stand out clearly from the main mass of the coarse-grained gabbro. These dikes contain a larger percentage of biotite than is found in the normal gabbro, but most interesting is the presence along the sides of the dikes of a well-marked parallel arrangement of the minerals. This is presumed to be a true flow structure consequent upon the flowage of the magma, where it was forced in the fissures, as none of the minerals bear indications of secondary origin, and show but faint evidence of the effects of pressure.

These dikes, as well as the main mass, are cut by a coarse-grained bronzite-norite. Bronzite, hornblende, and labradorite are the essential constituents of this rock, arranged in order of

their importance. The following analysis gives its chemical composition:

ANALYSIS OF BRONZITE-NORITE BY MR. GEORGE STEIGER.

SiO_2	48.17	Na_2O	1.34
TiO_2	1.00	H_2O 100°−	.19
Al_2O_3	25.26	H_2O 100°+	2.00
Fe_2O_3	1.13	P_2O_5	.07
FeO	6.10	CO_2	.43
CaO	9.53		
MgO	4.22		100.17
K_2O	.73	MnO, etc., not looked for.	

The last gabbro occurrence to be mentioned is one in which we find the normal type of hornblende-gabbro cut by a dike in which monoclinic pyroxene is in about equal quantity with the hornblende. This evidently represents a transition towards a true gabbro. This exposure of gabbro is cut by a peridotite, which is feldspathic and concerning which detailed statement will be made in the following pages.

The rocks just described may be compared in their variation to those described by G. H. Williams [1] from Maryland, by Chester [2] from Delaware, and by Fairbanks [3] from California. A series of basic rocks similar in many respects to those of Crystal Falls has also been described recently in two interesting papers by van Horn [4] and Schaefer.[5]

Peridotites.—The peridotites are all coarse-grained rocks of very dark color, consisting of the following chief mineral con-

[1] The gabbros and associated hornblende rocks occurring near Baltimore, by G. H. Williams, Bull. U. S. Geol. Surv., No. 28, 1886. Outline of the geology of Maryland, Baltimore, 1893, p. 39.

[2] The gabbros and associated rocks in Delaware, by F. D. Chester, Bull. U. S. Geol. Surv., No. 59, 1890.

[3] The geology of Point Sal, by H. W. Fairbanks, Bull. Dept. of Geol., Univ. of Cal., Vol. II, No. 1, 1896, p. 56 et seq.

[4] Petrographische Untersuchungen über die noritischen Gesteine der Umgegend von Ivrea in Oberitalien, by F. R. van Horn, Tsch. Mitt, Vol. 17, 1897, pp. 391–420.

[5] Der basische Gesteinszug von Ivrea im Gebiet des Mastallone–Thales, by R. W. Schaefer, Tsch. Mitt., Vol. 17, 1898, pp. 495–517.

CORRECTED ANALYSIS.

THERE is given upon this sheet the corrected analysis of the bronzite-norite described upon page 382 of the May-June number of this JOURNAL. The tables containing percentages of chief oxides, etc., have been calculated from this analysis, corresponding to those formerly given upon pages 387-8, and are also given here. It is requested that these analyses and tables be substituted in the places indicated by the table and page numbers which accompany them.

ANALYSIS OF BRONZITE-NORITE BY MR. GEORGE STEIGER.

Page 382.

SiO_2	48.23	Na_2O	1.34
TiO_2	1.00	H_2O 100 –	.26
Al_2O_3	18.26	H_2O 100 +	2.00
Fe_2O_3	1.26	P_2O_5	.07
FeO	6.10	CO_2	.43
CaO	9.39		
MgO	10.84		99.91
K_2O	.73	MnO, etc., not looked for.	

Table I, page 387

	3
SiO_2	48.23
TiO_2	1.00
Al_2O_3	18.26
Cr_2O_3	
Fe_2O_3	1.26
FeO	6.10
MnO	——
NiO	——
CaO	9.39
MgO	10.84
K_2O	.73
Na_2O	1.34
H_2O 100–	.26
H_2O 100+	2.00
P_2O_5	.07
CO_2	.43
	99.91

Table II, page 387

	3
SiO_2	49.64
TiO_2	1.03
Al_2O_3	18.79
Fe_2O_3	1.30
FeO	6.28
CaO	9.67
MgO	11.16
K_2O	.75
Na_2O	1.38

Table III, page 388

	3
Si	45.27
Ti	.71
Al	20.26
Fe	5.70
Ca	9.51
Mg	15.22
K	.88
Na	2.45

stituents: pyroxene (monoclinic and orthorhombic), olivine, hornblende, and biotite. Associated with them are feldspar, apatite, green and brown spinel, and iron oxide. The relative proportions of these minerals differs much, and yield different well-known rocks. The types are not sharply separated, but are found, both in the field and under the microscope, to grade into one another. The purest form of peridotite is the wehrlite, composed essentially of olivine and augite. Where, besides these minerals, hornblende is present in large quantities, the rocks belong to the amphibole peridotite type and approach Williams' cortlandtite. In some specimens the biotite is almost in sufficient abundance to warrant the naming of the rock biotite-peridotite. Again, feldspar is present in comparative abundance and the rock is a feldspathic wehrlite, and approaches an olivine-gabbro or an olivine-hornblende-gabbro.

A number of exposures of the peridotites have been examined, but only one will be described here, and that has already been referred to under the gabbros. This peridotite cuts the gabbros. Sections made from different specimens taken from the exposure would be named, if considered separately, amphibole-peridotite, wehrlite, or even olivine-gabbro. This is the same exposure from which was taken a specimen described by Patton[1] as hornblende-picrite. In this rock there occur the following essential mineral constituents, given in order of crystallization: augite and olivine, apparently contemporaneous, orthorhombic pyroxene, hornblende, biotite and feldspar.

Of the mineral constituents forming the rock, augite is the only one which is automorphic, and then only when it is partially or wholly surrounded by feldspar. The olivine is in rounded individuals which are never associated with the augite in such a way as to enable their relative periods of crystallization to be determined. Orthorhombic pyroxene, apparently bronzite, occurs in grains inclosed in hornblende, and also forms

[1] Microscopical study of some Michigan rocks, by H. B. PATTON, in Sketch of the geology of the iron, gold, and copper districts of Michigan, by M. E. WADSWORTH, Rept. State Board Geol. Surv. for 1891, 1892, 1893, p. 186.

a narrow zone around the olivine. The hornblende is predominately a brown variety, showing strong pleochroism; **a** is light cream yellow, **c** is yellowish-brown, and **b** is reddish-brown. **b**>**c**>**a**. Patton[1] has already called attention to the exceptional pleochroism of this hornblende, in which the brownish color is that of rays vibrating parallel to the orthodiagonal axis. The brown hornblende is accompanied by a small quantity of green hornblende, which is in crystalline continuity with the brown, and is apparently original. The biotite began to crystallize before the hornblende had ceased growing, as we find it in ragged plates included by it, especially upon the periphery of the individuals. It is normally the least well-developed mineral present. Feldspar is present at times in small quantity, and forms the mesostasis. The olivine possesses a certain interest, as it is surrounded by zones[1] of different minerals; first, orthorhombic pyroxene, surrounded in its turn by green compact hornblende, which is in optical continuity with the predominant brown hornblende of the rock. This green hornblende lies next to the feldspar, and is traversed by anastomosing tabular feldspar growths.

From the relations described as existing between the various minerals composing the peridotite, it seems that the following stages may be outlined in the progress of the consolidation of this rock: From the coarse, even-grained character, and from the fact that neither a fine-grained groundmass nor glass is present, the conclusion is warranted that it consolidated very slowly, and must have, of course, at some time been under very high temperature. The olivine and augite were the first of the chief silicate constituents to form, and crystallized out of the magma at approximately the same time. The magma soon reached a condition unfavorable for further production of olivine, probably on account of increasing acidity. There was then formed the orthorhombic pyroxene occurring in a zone surrounding the olivine. The monoclinic pyroxene continued to grow during the formation of this orthorhombic variety, as it is

[1] Loc. cit., p. 186.

not surrounded by it. Finally, however, the condition of the magma was such that in the place of the monoclinic and orthorhombic pyroxene the crystallization of hornblende began.

I do not know what the conditions were which caused the formation of the hornblende subsequent to and in such intimate association with the pyroxene, surrounding it in zonal growth. An explanation of such occurrences has been attempted by Becke[1] in a recent article in which the conclusion is reached that the formation of hornblende and pyroxene depends upon changes in temperature and pressure. His explanation is based upon the facts of occurrence of pyroxene and hornblende in plutonic and effusive rocks, and also upon the well-known fact that at high temperature and atmospheric pressure hornblende cannot exist, but when fused recrystallizes as pyroxene, and upon the experiments of von Chrustschoff,[2] who has obtained hornblende at a temperature of 550° C., with the presence of water, under which conditions a high pressure must be developed. However, attention should be called to the fact that his explanation does not take into account other important factors which certainly influence the crystallization of minerals, for example, the chemical composition of the magma, and the fusion point and specific gravity of the minerals.

Whatever the factors are which determine its crystallization, the fact is that hornblende began to crystallize in the place of pyroxene. The biotite appears to have been formed at this time with the hornblende. The production of the hornblende and biotite continued until the remaining magma had reached the composition of basic feldspar, which then crystallized and now forms the mesostasis. A zone of orthorhombic pyroxene succeeded by one of hornblende has been described as surrounding the olivine in this peridotite. The term "reaction-rims" has been

[1] Gesteine der Columbretes; Anhang: Einiges über die Beziehung von Pyroxen und Amphibol in den Gesteinen. By F. BECKE: Tsch. Mitt., Vol. 16, 1896, pp. 327–336.

[2] Bull. de l'Academie des Sciences, St. Petersburg, 1890, 13. Cf. BECKE, loc. cit., p. 337.

applied to similar zones by various observers. It seems to me that this term is inapplicable to such zones. It is not probable that in such a case as this there is a reaction in a strict sense between the magma and the olivine. Moreover, the zones should not be compared to the "resorption-rims" found so commonly in certain effusive rocks, where, from the fusion of hornblende crystals, pyroxene has been produced. Such a zonal growth around the olivine seems to me comparable to the case described by Washington,[1] where colorless diopside phenocrysts are surrounded by a narrow border of yellowish-green augite, which corresponds to the small augites in the groundmass, or to those cases which are so common in plutonic rocks, even in this rock described, where hornblende is found surrounding the pyroxene.

A general explanation which would account for the successive crystallization of pyroxene and hornblende in this rock should be applicable to such a zonal growth as occurs around the olivine, taking into consideration, of course, the probability that a factor of slight importance in the one case may be the controlling factor in the other. Such occurrences seem clearly to indicate a change in the chemical composition of the magma as the chief factor, but influenced more or less strongly by the pressure, the temperature, and also by other factors.

An analysis of this peridotite is given below:

ANALYSIS OF PERIDOTITE BY DR. H. N. STOKES.

SiO_2	44.99	MgO	21.02
TiO_2	.97	K_2O	.74
Al_2O_3	5.91	Na_2O	.91
Cr_2O_3	.25	H_2O 110°−	.63
Fe_2O_3	3.42	H_2O 110°+	3.19
FeO	8.30	P_2O_5	.05
MnO	trace	CO_2	trace (?)
NiO	none		
CaO	8.79		99.17

[1] Italian Petrological Sketches, 4, The Rocca Monfina Region, by H. S. WASHINGTON, JOUR. GEOL., Vol. V, 1897, p. 254.

Chemical relations of the series.— In the preceding pages the mineralogical evidence has been given of the variations under discussion. In the following tables there are reproduced the analyses which have been given of the typical members of the different classes. They are arranged in order of diminishing acidity. In Table I the complete analyses are given.

I.

	1	2	3	4
SiO_2	58.51	49.80	48.17	44.99
TiO_2	.72	.79	1.00	.97
Al_2O_3	16.32	19.96	25.26	5.91
Cr_2O_3	none			.25
Fe_2O_3	2.11	6.32	1.13	3.42
FeO	4.43	.49	6.10	8.30
MnO	trace	——[1]	——[1]	trace
NiO	none	——	——	none
CaO	3.92	11.33	9.53	8.79
MgO	3.73	7.05	4.22	21.02
K_2O	4.08	.61	.73	.74
Na_2O	3.11	2.22	1.34	.91
H_2O at 110°	.23	100°— .13	100°— .19	110°— .63
H_2O above 110°	2.00	100°+ 1.71	100°+ 2.00	110°+ 3.19
P_2O_5	.30	.07	.07	.05
CO_2	none	.15	.43	trace?
	99.46	100.63	100.17	99.17

II.

PERCENTAGES OF CHIEF OXIDES REDUCED TO 100.

	1	2	3	4
SiO_2	60.36	49.80	49.41	47.33
TiO_2	.75	.79	1.02	1.02
Al_2O_3	16.83	19.96	25.96	6.22
Fe_2O_3	2.17	6.32	1.16	3.60
FeO	4.57	.49	6.25	8.73
CaO	4.04	11.33	9.77	9.25
MgO	3.85	7.05	4.32	22.11
K_2O	4.21	.61	.74	.78
Na_2O	3.21	2.22	1.37	.96

[1] MnO, etc., not looked for.

III.

ATOMIC PROPORTIONS OF METALS.

Si	55.85	46.53	45.90	42.48
Ti	.53	.56	.72	.70
Al	18.41	22.03	28.50	6.60
Fe	5.08	4.83	5.70	9.02
Ca	4.04	11.42	9.79	8.98
Mg	5.32	9.85	6.01	29.67
K	4.99	.74	.89	.91
Na	5.78	4.04	2.49	1.67

In Table II there is given the percentages of chief oxides reduced to 100, and in Table III the atomic proportions of the metals.[1] The analyses show that all of the rocks contain a moderately large amount of water. Nevertheless, they are sufficiently well preserved to warrant a discussion of their analyses for classificatory purposes. Indeed, No. 4 is remarkably fresh for so basic a rock. With reference to analysis No. 1, it may be stated that the rock is, on the whole, one which it is somewhat difficult to place definitely in the existing division of rock families. The large amount of lime and relatively low percentage of alkalies prevent placing the rock with the syenites, which possibly the presence of the large amount of orthoclase might lead one to do if the rock were studied with the microscope alone. On the whole, it approaches close to the monzonites, according to their chemical composition as given by Brögger.[2] From this it differs, in that the lime, 3.92 per cent., is too low to bring the rock within his limits, 4.52 to 10.12 per cent. However, if we consider the total of the alkaline earths, 7.55 per cent., in this rock, we find that it comes well within Brögger's range, 6.05 to 17.52 per cent., for a total of magnesia and lime. Moreover, the alkali total, 7.19 per cent., is too high to warrant its classification in the monzonite class as a representative of the type of the biotite-monzonite.

[1] These tables were calculated for me by MR. V. H. BASSETT, assistant in chemistry in the University of Wisconsin.

[2] Op. cit., Part II, p. 51.

On comparing the analysis with that of a normal diorite, we find the relative proportions of the alkalies are abnormal. Also the lime content is too low for rocks of this character; and, again, the magnesia is too high. From the above considerations it seems clear that the rock is related to the monzonites and diorites. However, it is so intimately associated with, and so evidently a facies of the tonalite, which is the dominant type where the mica-diorite occurs, that it is considered to be more closely related to the lime-soda-feldspar rocks in which the orthoclase is but accessory, than to the monzonite family of orthoclase-plagioclase rocks. It is, therefore, considered to be a mica-diorite. It has already been remarked that while for normal diorites the lime is too low, the magnesia is correspondingly too high. May we not with right consider this as indicating a relationship to the more basic rocks gabbros, in which magnesia forms a very important constituent and with which it is so intimately associated in the field? As against this interpretation, however, we have a very high percentage of alkalies and moderately high percentage of silica, which certainly warrant the exclusion of this rock from the gabbro family.

When we turn to a consideration of the gabbro-norites as represented by analyses Nos. 2 and 3, it is at once clear that if we accept, as has been done in the preceding pages, Brögger's[1] characterization of the diorite and gabbro families, that these rocks could not be included with the diorites as respectively normal diorite and bronzite-diorite, but must, from their abnormally low silica and alkali content and high alumina, lime, and magnesia content, be placed with the gabbros. Especially noteworthy in analysis No. 2 is the high percentage of alumina present. Normally, large alkali content accompanies high percentage of alumina. A reference to the alkalies shows this not to be true in this instance.

Analysis No. 4 is not to be taken as representing the most basic variety of peridotite in this district. From this alone the statement that the variations extend to the ultrabasic rocks

[1] Op. cit., Part II, pp. 35, 39.

would hardly be warranted. As has already been said, however, the rock of which the analysis was made is one which is feldspathic, and represents a transition upward into the gabbro.

Examining the series of analyses together, we see that in passing from the most acid to the basic end the alumina increases very rapidly to 25.96 per cent., until it reaches the extreme basic rock, when it drops suddenly to 6.22 per cent. The analyses also show an increase in the same direction in iron, as is best brought out in Table III. The alkalies increase with diminishing silica, whereas the magnesia, which for rocks of this character is very characteristic, shows a decided increase. In the gabbro-norite-peridotite portion of the series, analyses Nos. 2, 3, and 4, the lime shows a constant diminution, corresponding to the increasing magnesian character of the rocks. Likewise the potash increases as the soda diminishes. The rocks represented by the analyses are believed to belong to a series ranging from a diorite on the one hand through hornblende-gabbro and norite to a peridotite on the other. It is evident that a gap exists between the gabbro and diorite. The diorite represents a gradation towards the orthoclase rocks of essentially the same acidity. On this acid side of the series the microscope also shows variations to a tonalitic and even granitic rocks very rich in quartz and orthoclase, probably very much more acid in character than the diorite represented in the analyses.

Relations of the rocks of the series.—The rapid changes in mineralogical composition and texture in a single rock exposure, and the changes thus occasioned from one type into another through intermediate facies, show very clearly the intimate relationship of the Crystal Falls rocks to one another, and warrants the assumption that they all belong to a geological unit, a conclusion long since reached by Williams[1] for a similar group of rocks, "The Cortlandt Series" from New York. Variations very similar

[1] The peridotites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. WILLIAMS, Am. Jour. Sci., Vol. XXXI, 1886, pp. 26–41.

The norites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. WILLIAMS. Am. Jour. Sci., Vol. XXXIII, 1887, pp. 135–144, 191–199.

to those here described have been well described by Messrs. Dakyns and Teall from some Scottish plutonic rocks.[1] The field studies have shown the relations of the various members of this series from Crystal Falls to be as follows: The diorite is found cutting the hornblende-gabbro. The gabbro is also found to be cut by a dike of biotite-granite. The relation of this particular dike to the diorite could not be determined; therefore it has not been described. In one case, however, a dike cutting a gabbro showed biotite-granite as a facies of the diorite. It is probable that the other dikes of biotite-granite occurring in the area are facies of the same widely distributed diorite magma. The hornblende-gabbro is cut by the bronzite-norite and the peridotite. It is thus evident that the eruption of the hornblende-gabbro was followed by that of a peridotite on the one hand and by a diorite, possibly even a granite, on the other.

It is a difficult matter to estimate quantitatively the amount of the one or the other rock type present in the Crystal Falls district. We are thus prevented from drawing from the predominance of the one kind or the other the conclusion that those represented in the minority are the results of the differentiation of a magma most nearly resembling in its original constitution that which predominates. Moreover, since the analyzed rock types were not selected as representatives of the extremes of the process of differentiation, it would not be wise to endeavor to give the mean composition of the parent magma, from the analyses of the differentiation products which have been presented. The main thesis, however, seems to be established that the separation of a magma into the various products described has taken place, as is indicated by the relations in the field, and as has been shown by the microscopical and chemical analyses.

From the relations described as existing between the various

The gabbros and norites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. WILLIAMS, Am. Jour. Sci., Vol. XXXV, 1888, pp. 438–448.

[1] On the plutonic rocks of Garabal Hill and Meall Breac, by J. R. DAKYNS, ESQ., M.A., and J. J. H. TEALL, ESQ., M.A., F.R.S., F.G.S., Q. J. G. S., Vol. XLVIII, 1892, pp. 104–121.

kinds of rocks, it was seen that the hornblende-gabbro was unquestionably the one which first reached its present position. Whether this is to be regarded as itself representing the composition of the parent magma, or only as a differentiation product of a still deeper seated igneous mass, cannot of course be determined. Be that as it may, the fact, which has been proven, remains, that given the period of eruption of this hornblende-gabbro as a starting point, and possibly this magma as the original one, the forces of differentiation have been active in two directions, towards increasing acidity and increasing basicity, in agreement with the law of succession of igneous rocks as propounded by Iddings.[1]

J. MORGAN CLEMENTS.

[1] The Origin of Igneous Rocks, by J. P. IDDINGS, Bull. Phil. Soc. Wash., Vol. XII, 1892, p. 145.

STUDIES FOR STUDENTS.

THE DEVELOPMENT AND GEOLOGICAL RELATIONS OF THE VERTEBRATES.

The object of these studies is in no wise to attempt to furnish a course in vertebrate palæontology, but rather to place before the student of geology, who has no time for the study of the morphological and phylogenetic questions involved, a brief statement of the results achieved by the workers in the more narrow field. The value of vertebrate remains as indicators of the time changes in the past is so well recognized that it is hoped that an orderly summary of the fossil vertebrates, with a brief indication of the lines along which they have developed, and references to the most helpful literature, may be of value to the student, both within the limits of these articles and in aiding him to extend the work by collateral reading.

PART I. THE FISHES.

FISHES are, in the popular language of Bashford Dean, "back-boned animals, gill-breathing, cold-blooded, and provided with fins." This definition may well be used if we remember that the "back-bone" is not always bony, that it may be entirely cartilaginous or only partly ossified. A similar condition may be found in all the other bones of the body and is the chief reason that the early history of the fishes is hidden in the deepest obscurity, for it is one of the most commonly recognized facts of palæontology, as well as one of the most deplorable, that only under the most favorable conditions can the soft structures of any body be preserved. From this it is easily understood why the earliest remains of fishes that we possess are those of forms in which the skeleton has progressed so far as to be formed of solid cartilage at least, and generally of cartilage with local ossification or calcification.

The following classification of the larger groups of the fishes is in general use :

Class: PISCES.
- Sub-Class: *Marsupiobranchii.*
  - *Ostracodermi.*
  - *Elasmobranchii.*
    - Order: *Selachii.*
      - *Batoidi.*
- Sub-Class: *Holocephali.*
  - *Dipnoi.*
    - *Sirenoidei.*
    - *Arthrodira.*
- Sub-Class: *Teleostomi.*
  - Order: *Crossopterygii.*
    - *Actinopterygii.*
      - Sub-Order: *Chondrostei.*
        - *Teleocephali.*

The first of these, the *Marsupiobranchii*, are not well understood in their relations to the true fishes. The most common of the group are the hagfishes and the lampreys of the present time. They differ from all other vertebrates by the entire absence of the lower jaw and of the pelvic and pectoral girdles of bone that support the hind and the fore limbs. Whether these conditions are the primitive stages of a developing fish or are the final stages of a degenerate structure, is still an unsettled question, and it is at this point of difficulty that we turn to the palæontological record. However, we can gain but little from the palæontology of the forms. A single specimen from the Old Red Sandstone of Scotland is the representative of the fossil *Marsupiobranchii*, and it is even doubtful whether this specimen is correctly referred to that group. The specimen shows the presence of well defined rings in the position of the vertebræ, a stage in advance of the recent forms, which would indicate for them a degenerate structure.

The earliest remains of fishes known are from the Lower Ordivician rocks of the Grand Canyon region of the United States. These are the very imperfectly preserved remains of what seem to be scales and bones of fishes whose affinities cannot be made out from the material.

Before attempting to take up the different forms of the true fishes it may be well to consider briefly those points in the anatomy of fishes in general where changes have taken place resulting in the modern type of the bony fishes. There are three regions in the skeleton that have been used more than any others in making out the different groups of the fishes and their phylogenetic development: 1. The gradual ossification of all the bones of the body. 2. The development of the vertebræ. 3. The development of the fin of the modern type.

The first of these is the gradual process of strengthening the skeleton by the addition of solid matter which has been at work ever since the origin of the class and is still incomplete in many forms. It is only in the last sub-order of the *Teleostomi*, the *Teleocephali*, that the process is at all complete. Before the actual formation of bone in the supporting tissues of the body the cartilage was frequently strengthened by the deposition of calcareous particles. This is the condition found in the remains of most of the early sharks.

The second process, the development of the vertebræ, is of considerable importance not only in the development of the fishes, but as we shall see, in the earliest of the *Amphibia* as well. The most primitive condition of the spinal column is such as is well illustrated in the *Amphioxus*, one of the simplest of all the vertebrate phylum, the column in this case consisting of a continuous rod of cartilage, the notochord, extending through the body from the anterior to the posterior end and lying near to the dorsal side of the body. It is protected by several layers or sheaths of membrane in which the future vertebræ are developed. The development of the bony covering of this rod is foreshadowed by the appearance of the cartilaginous rings that have the same serial arrangement as the vertebræ of the more advanced types. A very important thing about the development of the vertebræ is the development on the superior and the inferior faces of the chordal sheath of bony arches that appear before the body proper, or centrum, of the vertebræ. The superior of these, the neural arch, protects the spinal cord

throughout the length of the vertebral column. The second is developed to the fullest extent only in the caudal portion of the column and there furnishes a protection for blood vessels. These arches may or may not be attached to the centrum in the adult form, but the bases are the first points of ossification and the rest of the vertebræ develops between them. The process is not complete in all of the fishes, and the gradual completion of the vertebræ is of great aid in determining the position of some of the fossil forms (Fig. 1).

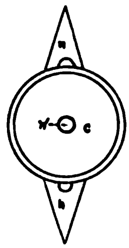

Fig. 1. Schematic view of a vertebra. *n*, neural arch; *c*, centrum; *h* hæmal arch; *w*, notochordal canal.

The third, and perhaps the most important of the three regions of development is the formation of the fins, both paired and median. Whatever may have been the original form of the fish the first thing in the evolution demanded by their peculiar environment must have been the development of some form of keel that would not only aid the fish in its progress through the water, but would enable it to maintain any desired position both as to the relative depth below the surface of the water and as to lateral displacement. The first step in the accomplishment of this end was the development of long fins extending from the head to the tail. One pair of these was developed on the median dorsal and ventral lines, and persists in the dorsal, caudal, and ventral fins of the existing fishes. The second pair extended along each side of the body in a plane at right angles to the first and divided the body into approximately equal parts above and below. The paired fins, the pectoral and the ventral, are supposed to be remnants of these lateral folds or fins.

The development of the fins seems to have followed a very definite line that has served as a great aid in making out the classification of the various fossil and recent forms. Undoubtedly the first stage of the development of the fins was the formation of the long folds of the skin that were without any internal support, and capable of very complex, wavelike motion, and without any great power of resistance to impressed forces. Of this stage we do not have any trace in the preserved fossil forms for the reason already assigned, that soft parts are not preserved except under the most exceptional circumstances. We should expect it to occur in the remains of the *Marsupiobranchii*, if at all, but the single specimen preserved, *Paleospondylus*, does not show any evidence of such a fold. The function of the fin fold, to preserve the equilibrium of the fish, would demand some degree of resistance in the fold, and the next stage of the fin must have been the appearance of fine, hair-like rays of horny material, confined to the dermal part of the fold and not joined to the body proper. These were many in number, and only served to stiffen the fin without strengthening its attachment to the body. These fine rays have been called the actinotrichia. The second stage in the development of the fins was the fusion of certain of these actinotrichia at points of the greatest strain in the fins into larger and more solid elements that afforded a much greater power of resistance at those points. The comparatively large and strong cartilaginous rods thus formed have received the name of radials. The same necessity of resisting outside forces that caused the union of the actinotrichia to form the radials demanded a stronger attachment of the radials to the body wall of the fish, and this was accomplished by the separation of the proximal portion of the radial as a separate element, which became elongate and penetrated into the body wall, affording a very strong support to the radials. This proximal section is called the basal (Fig. 2).

Up to this point in the development of the fins the history of the paired and the unpaired fins is regarded as practically the same, for the paired fins were as yet but undifferentiated parts

of the lateral body folds. The reason for the development of one portion of the lateral fins over another is not well understood, but it has been suggested that at points of especial strain in the fold, points where, from the mechanical advantage of their

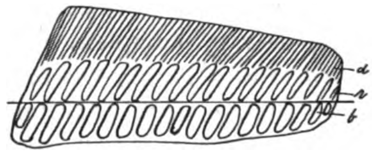

FIG. 2. Schematic unpaired fin; *b*, basal, *r*, radial; *d*, dermal margin of fin (after Smith-Woodward).

position, certain parts of the fold were able to assist in the propulsion of the body through the water, that the fins were especially well developed, and that there appeared lappetlike prominences in the position of the present paired fins. As these lappets assumed more and more of the function of swimming organs, and less of balancers, they required an even stronger support than before, and this was accomplished by the fusion of the basals together and also of the radials, though to a less extent. As the lappets of the lateral fin grew in importance, the intermediate portion dwindled away until all trace of the original fold is lost between and beyond the paired fins. The final step in the development of the fins was the appearance beyond the distal ends of the radials of fine dermal elements that have much the appearance of the original actinotrichia. These serve the purpose of supporting the web at the extremity of the fins.

Another line of development of the fishes is closely allied to the development of the fins. The median fin that originally extended from the head of the animal to the tail has in the course of its development gradually retreated toward the posterior portion of the body until it is represented by a single caudal fin and one or more separated elements called from their positions the dorsal and the anal fins. The caudal fin has assumed different positions in relation to the terminal portion of the

spinal column. In the original condition the dorsal and the ventral parts of the fin were equally developed, and the vertebral axis divided the fin into two equal parts, so that the fin presented a rounded or slightly acuminate appearance. This is called the diphycercal condition. Another, and a very common condition among the more primitive forms of fish, is where the ventral portion of the caudal fin is developed at the expense of the dorsal, and the terminal portion of the vertebral axis is bent upward at the end. This is called the heterocercal condition. The form most commonly found in the modern forms of fishes is that in which both the dorsal and the ventral portions of the caudal fin are developed more than the main portion of the fin, but about equally themselves. This is called the homocercal condition, and was for a long time considered as the primitive condition, or at least more primitive than the heterocercal. It is shown to be untrue by the fact that even in the highest types of the bony fishes the extremity of the notochord is bent upward as in the heterocercal form of the tail. The progress of development of the tail seems to have been from the diphycercal through the heterocercal to the homocercal.[1]

The oldest remains of fishes that are definitely known come from the Upper Silurian and the succeeding rocks as high as the Carboniferous. The group called *Ostracodermi* has long been denied a position among the fishes by certain authors, the principal objection being the seeming lack of any lower jaw, which is regarded as one of the principal characters of the vertebrates. Because of this feature and the appearance of some of the forms which is similar in a general way to that of the Trilobites, the group has been considered as belonging to the *Crustacea*, but there are so many other characters that unite them with the

[1] A discussion of the facts here pointed out, with much more that is valuable to the student, will be found in a recent book by Bashford Dean, *Fishes, Living and Fossil*, an outline of their forms and probable relationships, Columbia University Biological Series, Macmillan & Co., 1895. This book takes up the various forms of fishes in a popular way that will not be beyond the student of geology who has the principles of biology. The large number of excellent illustrations will be found to be of great value in getting an idea of the fossil forms.

fishes that no less an authority than Smith-Woodward has placed them among the fishes. In general, the group is distinguished by the fact that the bones are not ossified; that the paired fins and the lower jaw are absent, and that the anterior part of the body is covered by large, bony plates that are developed in the skin and have no connection with the cartilaginous skeleton. The group is divided into three families: *Pteraspidæ*, *Cephalaspidæ*, and *Pterícthidæ*.

Pteraspidæ.—This family is confined almost exclusively to the Devonian, the Old Red Sandstone of England and Scotland. It contains the simplest and most archaic forms of the *Ostracodermi*. The anterior part of the body was covered by two large plates, a superior and an inferior, that served as a complete armor for that part of the body. The eyes protruded from openings formed by notches in the adjacent edges of the two plates. The upper plate is sometimes marked by grooves that are supposed to indicate the course and distribution of sensory tracts such as are found in the skulls of the shark and many of the more advanced types of fishes. The posterior part of the body was covered by many small rhomboid scales. It is probable that the forms were bottom feeders, and that the common food was the abundant molluscan fauna of the Devonian seas. *Pteraspis* and *Holaspis*, from the Devonian of England, and *Palæaspis*, from the Upper Silurian of Pennsylvania in the United States, are the best known of the family.

Cephalaspidæ.—In many respects the members of this family resemble the last, the anterior part of the body is covered by well developed plates, while the posterior portion is protected by rhomboid scales. The size was, in general, smaller than either of the other families, seldom reaching more than a foot in length. The head was large and curiously like that of a Trilobite in external appearance. The anterior edge was rounded, and there were two lateral posterior extensions in a position analagous to that of the genal spines in the Trilobites. The eyes were located near the center of this plate. The scales that formed the protection of the posterior part of the body are

large and arranged in rows, the mid-dorsal row developing an acuminate ridge that has the appearance of a dorsal fin. The tail was distinctly heterocercal. In some of the more perfectly preserved specimens there seems to be an indication of the presence of external gills at the base of the posterior lateral spines of the head plate. All the known forms are from the Upper Silurian and the Devonian rocks of England and Europe. Among the best known of the genera are, *Cephalaspis*, *Auchenaspis* and *Tremataspis*

Pterichthidæ.—This family presents many important steps in advance of the other two, the anterior part of the body is not protected by single plates, but by an armor made up of the union of several small plates both upon the upper and the lower sides. The posterior portion was, as in the other forms, covered with small scales. Perhaps the most peculiar thing about the family is the presence upon the sides of the body, near the anterior end, of elongate, movable appendages that perhaps served as swimming organs, although in one of the later and more specialized of the forms the appendages become anchylosed to the adjoining plate, and lose all power of motion. These appendages are regarded as the homologues of the posterior extensions of the head plate of the *Cephalaspidæ*. The *Pterichthidæ* are most commonly known from the Devonian of the Old World. *Pterichthys*, *Asterolepis*, and *Bothriolepis* are well-known European forms. From the New World *Bothriolepis* has been described from the Devonian of Canada, and from the same horizon in Ohio incomplete remains have been described by Newberry as *Acanthaspis* and *Acantholepis*. It is necessary here to warn the student against a confusion that may arise between the old classification present in so many of the text-books and the one here used. The *Pteraspidæ*, *Cephalaspidæ*, and the *Placodermi* were regarded as orders of the highly artificial group, *Ganoidei*. The last order included not only the *Pterichthidæ*, but more highly developed forms that are now known to belong to the *Dipnöi*.

The *Elasmobranchii* are the most primitive forms that hold an

undisputed position among the fishes. Including both the sharks and rays, the group may be defined as made up of forms in which the skeleton is cartilaginous, the skin filled with fine calcareous particles (shagreen), the tail heterocercal, and the external openings of the gills mere slits in the skin of the neck unprotected by an operculum. In the previous sub-class there are no remains preserved of distinct vertebræ, but in the sharks the beginning of the vertebræ is seen in the formation of cartilaginous rings in the sheath of the notochord. These rings are of varying degrees of development in the different forms, in some forming mere circular bands around the chord, while in others they are nearly closed by the ingrowth of the cartilage that tends to segment the chord off into intervertebral elements. There is always attached to the superior and the inferior faces of the cartilaginous ring the neural and the hæmal arches that carry the spinal cord and the blood vessels.

The most primitive of the fossil sharks comes from the Lower Carboniferous of Ohio. This form, *Cladoselache*, is, in many respects, quite close to the hypothetical type form of all the fishes, the body is long and slender, and there were seven gill slits in the neck, which seems to be the number characteristic of the earliest forms. The unpaired fins have not progressed beyond the second stage of development, as outlined in the first part of this paper, that is, the fin fold is supported by small rods of cartilage, radials, that are not attached to the body wall. The paired fins are in a scarcely more developed condition, the lateral fold has disappeared, but the two lappets that represent the pectoral and the ventral fins have not progressed beyond the stage of the radial support, and are consequently of no value to the fish as swimming organs, but must have served merely as balancers. The tail was abruptly heterocercal. The whole form was rather small, not reaching a length of more than six feet at the outside.

Acanthodes, a rather small form from the Coal Measures of England, seems to present a step in advance of *Cladoselache*. The shagreen particles that are scattered throughout the skin

of most of the sharks are in this form enlarged into scalelike forms that fit tightly one against the other and afford a complete cover for the body. The paired fins are more strongly developed than in the previous form, and are better fitted for the purpose of balancing the body as well as assuming, to some slight extent, the function of locomotion.

Climatius, from Devonian Old Red Sandstone of Scotland, is of considerable interest from the fact that between the paired fins on the two sides there are developed many smaller fins, located along the line of the primitive fin fold. These are regarded as the remnants of the disappearing lateral body fold. The form represents a stage in this respect ancestral to both *Cladoselache* and *Acanthodes*, but is in other respects in advance of both of them.

Pleuracanthus, from the Permian, is one of the most interesting of the fossil sharks. It represents a stage considerably in advance of the forms already described. The radials of the median fins have separated off the proximal basal segments that afford the strong attachment of the fin to the body wall, and there is developed to some extent the dermal elements of the external edge of the fin that are found in the fins of the modern bony fishes. The paired fins present a very interesting condition, the fore limb having the character of a dipnoan fin, and the hind limb the characters of the more advanced type of the fish fin. To understand this condition it is necessary to go back to the formation of the paired fins from the lateral fin folds. The gradual development of the functional swimming fin was by the concresence of the basal and the radials to form strong, though somewhat flexible supports for the membrane of the fin. This was accomplished in two ways. In one the basals united and formed a long median axis upon each side of which the radials were attached after the manner in which the barbs of a feather are attached on each side of the quill. This type was originally supposed to be the most primitive form of the fin, and so it was given the name of *archipterygium*. In the other type the basals fused into one or more pieces that were

confined to one side of the fin, and the radials formed the other side ; this is the type of fin present in the more advanced fishes ; it is called the *ichthyopterygium*. See Fig. 3.

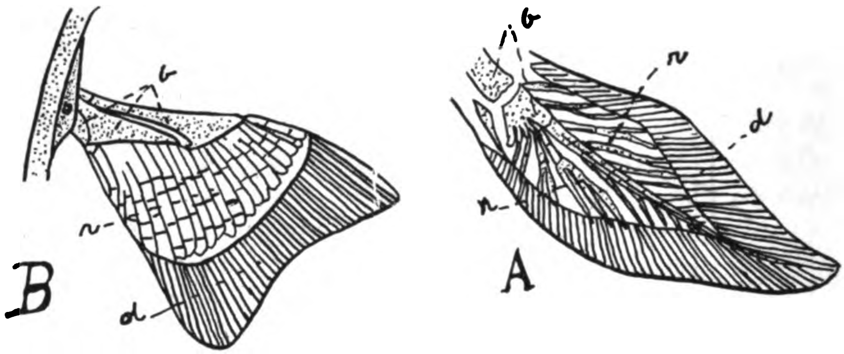

FIG. 3. *A*, archipterygium ; *B*, ichthyopterygium ; *b*, basals ; *r*, radials ; *d*, dermal margin.

Besides the peculiar condition of the fins, *Pleuracanthus* presents other remarkable features. Notable among these are the presence of a large spine that projected from the posterior edge of the skull, and the fusion of the shagreen denticles on the superior surface of the head into numerous dermal plates. In *Pleuracanthus*, as well as the forms previously mentioned, the center of the vertebræ had not yet become very well developed, and all that is found in the preserved specimens is the line of neural arches above the position of the notochord and the hæmal arches below.

Chondrenchelys from the Carboniferous of Europe was in many respects similar to *Pleuracanthus*, but there is one point of decided advance, the vertebræ were well formed, though still cartilaginous, and the inner part of the cartilaginous vertebral ring was well filled so that the chord was divided into segments by constrictions at the center of the vertebræ.

With the appearance of the sharks of the type of *Chondrenchelys*, the modern form is outlined, and since the Carboniferous there has been no great change in the general structure

of the group. One thing is important, however, and that is the changes that took place in the teeth of the many forms that were developed during the Carboniferous time. There seems to have been developed two types of teeth that indicate a very different mode of life. In one of these groups the teeth became flattened and adapted to crushing or grinding the shells of molluscs and crustaceans that formed the food supply. The surfaces of the teeth were sculptured in the most intricate manner, affording an enlarged and more efficient triturating surface. The different patterns of this sculpture seem almost endless. To these forms have been given the name of the "pavement-toothed sharks." *Janassa*, *Petalodus* and *Cochliodius*, all from the Carboniferous rocks are perhaps the best representatives of the group. *Cestracion*, the modern Port Jackson shark, is the single living representative. In the second group the teeth were developed in accordance with the demands of a more active and rapacious habit. They are more or less triangular in outline, and the edges are frequently finely serrated, affording a very firm hold as well as forming most efficient cutting organs. This type reached its development later than the pavement-toothed forms. The largest form, *Carcharias*, in which the teeth reached a length of six inches, is known from the Eocene of both the Old and the New Worlds. Other typical forms are *Sphenodus*, *Lamna*, and *Carcharodon* from the Mesozoic of Europe and many forms that are regarded as subgenera of *Carcharias* in North America.

One type of fossil that must be mentioned is the *Ichthyodorulite*. These are detached spines that are found in great abundance in the Carboniferous and Mesozoic rocks, and from which a large number of genera have been named. In the modern sharks the anterior end of the fins, and especially the dorsal fin, is frequently strengthened by the development of a strong spine that serves as a cutwater. These spines were much more strongly developed in the more primitive sharks, and were subject to the greatest degree of modification in form, structure, and ornamentation. As they were so strong they would naturally

be preserved through the accidents of fossilization more often than the softer structures of the skeleton.

The Rays or *Batoid* branch of the *Elasmobranchii* are of doubtful origin, other than the fact that they differ from the true sharks only in the modifications that are attendant on the extreme flattening of the body due to the habit of bottom feeding. They probably originated as far back as the Carboniferous time, although well-preserved forms are not known from rocks earlier than the Jurrassic. *Rhinobatis*, an existing genus, is known from the Oolite.

The part played by the sharks in the waters of the Palæozoic oceans seems to be very much the same as that played by the recent bony fishes in the modern waters. The variety of forms was seemingly endless, and the adaptations to various conditions of life, and to different means of obtaining food, bear witness, not only to the large number of forms, but to the strength and dominance of the type.

The *Holocephali*, the Chimeroids, is a peculiar, aberrant group, that is allied on the one hand to the sharks and on the other to the Dipnoans. The structure of the fins and the vertebral column is the same as in the sharks, but the structure of the head and the arrangement of the teeth is almost the same as the dipnoans. There is a single broad dental plate in the lower jaw, and two plates in the upper jaw instead of numerous isolated teeth. The surface of these tooth plates is variously modified by the addition of knobs, ridges, and other irregularities, to increase the grinding surface. Little is left of the fossil forms but the teeth and the spines that stood at the anterior end of the dorsal fin as in the sharks. Fossil forms are *Ischyodus*, *Myriacanthus*, and *Squaloraja*, all from the Mesozoic.

The *Dipnoi* are, perhaps, the most peculiar of all of the fishes. For a long time considered as the linking type between the fishes and the amphibians, they are now generally regarded as a degenerate group that originated from the stem of the Crossopterygian *Teleostomes*. They are characterized by the absence of a connecting bone, the quadrate, between the skull proper

and the lower jaw. This condition, called autostylic, is found in the preceding group. Other characters are the modification of the swim bladder, in the living forms at least, as a breathing organ that assumes to some extent the structure of the lungs of the land vertebrates, the presence of tooth plates instead of teeth in the jaws, the archipterygial structure of the fins and the diphycercal tail. At the present time there are only three genera of the group living, but their wide distribution points to a very great development in earlier times. The existing genera are *Protopterus* from Egypt, *Ceratodus* from Australia, and *Lepidosiren* from South America. In these forms, as in the fossils, the vertebræ are incompletely ossified, the centrum remaining cartilaginous, while the upper and the lower arches are fairly well ossified. The major portion of the skeleton is well ossified, thus showing a condition in advance of the sharks and Chimeroids.

The *Dipnoi* are an exceedingly ancient group ; even as early as the Devonian they had developed most of the characters that distinguish them from the other fishes. While it is altogether probable that they originated from the primitive shark stem, the point of origin seems to be totally lost, for the well-developed Dipnoans are found contemporaneous with the earliest of the sharks. Of the early *Dipnoi*, perhaps the most interesting is *Dipterus* from the Old Red Sandstone. This form had well-developed cycloidal scales, the type of the modern fish scale, while the sharks still had the shagreen denticles, and the Ostracoderms the thick, bony, rhomboid scales so characteristic of the early fishes. It had the skull protected by a roofing of dermal plates, and the teeth modified into large plates, with rough triturating surfaces. The plates were arranged as in the *Holocephali*, two in the upper jaw and one in the lower jaw of each side.

Phaneropleuron, from the same horizons in Scotland, is more primitive in some of the characters ; for instance, the jaws are provided with many small, conical teeth, and the dorsal fin is continuous instead of being broken up into two or three seg-

ments. Specimens of this genus are known from the Devonian rocks of the province of Quebec in Canada. *Ctenodus*, from the Carboniferous of England, *Holodus* and *Palædaphus* from Devonian of Europe, *Mylostoma* from the Devonian of New York, and *Gnathorhiza* and *Strigilina* from the Permian of Texas, are all characteristic forms that have been described from the teeth.

A division of the *Dipnoi*, the *Arthrodira* are of especial interest, as they were at one time regarded as belonging with the *Pterichthidæ* in an order the *Placodermi*. The discovery of well-developed lower jaws and paired fins demonstrated that they could not belong among the primitive *Ostracodermi*, and the discovery of the manner of the articulation of the lower jaw to the skull showed that they belonged among the *Dipnoi*. They are among the most ancient of the fishes, ranging from the Upper Silurian to the Carboniferous. In the United States a large majority of the known remains have been taken from the Waverly Shales of Ohio. In Europe they are found in the Devonian Old Red Sandstone of England and Scotland. They were powerful, armored, predatory forms, in many cases of large size, that must have been a match for the largest sharks of the time. The armor in some of the genera was between two and three inches in thickness. The armor seems to have been confined in most of the forms to the anterior portion of the body, which has led to the belief that perhaps they buried the posterior part of the body in the mud and lay in wait for their prey rather than seeking it out and depending on their rapidity of movement and powerful jaws to obtain the mastery.

Coccosteus, a rather small form from the Devonian of England, is one of the best known of the group. It did not reach a length of more than one or two feet. The anterior part of the body is covered with an armor made up of several plates that extend back to about the middle of the body. The centra of the vertebræ are not preserved but the upper and lower arches outline the notochordal column. The dorsal fin is in the stage of the basals and radials and the posterior pair of fins is united to a distinct pelvic girdle. The armor of the

anterior portion of the body was very hard and polished in appearance, looking like the enamel scales of the "Ganoid" fishes and covered with small tubercles that were divided by the course of rather deep sensory canals. The armor plates were purely dermal in character having nothing to do with the true skeleton which was still made up of cartilage. One very peculiar thing was the presence of a very strong joint between the plates covering the head and those covering the shoulders. This joint must have permitted a great degree of motion in the vertical direction between the head and the body, though the purpose of such a motion is not understood. The posterior part of the body was covered by a thick integument entirely devoid of scales such as are present in the *Ostracodermi*.

The American forms of the *Arthrodira* were in general much larger and better developed than the European ones. They reached a total length of as much as ten or twelve feet and the sculpture of the armor and the variety of forms presented in the development of the jaws bear witness to the great variety of genera developed. The arrangement of the teeth is somewhat as in the Dipnoans, that is there were no separate teeth bordering the jaws but there were dental plates that were attached to the edges of the jaw; one peculiar thing about the plates is that they were not fixed as in the Dipnoans but were to a greater or less extent movable. In general the body form was like that of *Coccosteus* but the modifications of the tooth plate presents a very remarkable series. In *Dinicthys* they are developed as sharp cutting edges with a strong notch near the anterior end, in *Titanicthys* as a simple cutting edge, in *Trachosteus* and *Diplognathus* the edges of the plates were serrated and presented the appearance of being set with isolated teeth as in the ordinary arrangement of the fish jaw.

The last of the subclasses of the fishes is the *Teleostomes*. This group includes the old orders *Ganoids* and *Teleosts* that have been used for so long and are still commonly met with in the text-books of geology. The main distinction between them as seen by the geologist is the presence in the Ganoids of bony,

rhombic scales and in the Teleosts of horny, cycloidal scales. It is readily shown that these characters are of the most superficial nature and the condition of one group is easily found in the other, still as a general thing it may be said that a majority of the older forms had the rhomboid type of scale and the modern forms have the horny type. Bashford Dean discusses the relationships and descent of the Teleostomes in the following words, p. 145: "Johannes Müller, when separating Ganoids from Teleosts, recognized clearly even at that early date (1844) that the majority of the structural differences of these forms were bridged over in exceptional instances; there were thus Teleosts with bony body plates, as well as, it was afterwards found, a Ganoid, (*Amia*) with herringlike cycloidal scales. But he believed that three structural characters of the Ganoids separated them constantly from all Teleosts, and warranted the integrity of the groups."

These distinguishing characters were:—

I. A contractile arterial cone, containing rows of valves.

II. An intestinal spiral valve.

III. The interfusion (chiasma) of the optic nerves.

It was not until these differences were shown to be of little morphological importance that the two groups were merged in that of the *Teleostomi* (Owen, 1866). Thus transitional characters of the arterial cone of *Butrinus* were discovered by Boas. The Teleost, *Cheirocentrus* was found to present Ganoidean intestinal characters, and the optic chiasma, as Wiedersheim demonstrated, could no longer be regarded as of taxonomic or morphological value.

The descent of the Teleostomes, like that of the other groups, has long been a matter of speculation. Their affinities with the Dipnoans are generally admitted (Gunther, Gegenbaur, Haeckel, Smith-Woodward). Rabl derives them directly from a Selachian stem, regarding the Dipnoans as later evolved Ganoidean forms. Beard, on the other hand, even goes so far as to entirely separate the Teleostome stem from that of the shark, lungfish, an amphibian, deriving it with a close kinship

to the *Petromyzonts* (*Marsupiobranchii*), from the earliest vertebrates. Palæontology, however, has lately been giving rich contributions to this disputed problem, and there can at present be little doubt that the conditions in fossil fishes have demonstrated that in most ancient times Dipnoan and Teleostome were closely approximated. Although even in the earliest fossils they may be distinguished (*e. g.*, by the arrangement of the head-roofing derm bones), yet, as Smith-Woodward has noted, forms occur too clearly transitional to indicate anything less than genetic kinship. The Crossopterygian, whose ancient structure is well known, may well have been derived from an ancestor common to the Ctenodont (Dipnoan) and the Holoptychian; so that the gradual nearing of the Teleostome stem to that more fixed, of the Dipnoan, is a strong suggestion of its derivation. The later descent of the Ganoids from an ancestor closely akin to, if not identical with the Crossopterygian, is usually conceded. Teleosts, first occurring in the Cretaceous, are by evidence of fossils the almost undoubted survivors of an extensive group of transitional Mesozoic Ganoids. But whether all Teleosts are to be deduced from a single ganoidean phylum can at present hardly be established. Thus catfishes, or Siluroids, appear in many structural regards closely akin to the sturgeon; but as their fossil remains are lacking before the Eocene—when however, they appear to have been in every way as highly evolved as in recent forms—little clew has been given to their descent.

Teleostomes may, in the present connection, be briefly characterized in their two principal subdivisions.

I. *Crossopterygian*, the more archaic group, uniting the characters of shark, lungfish, and ganoid, retaining the ancient cartilaginous fin bases, radials, and basals in their lobate fins; in some forms (*Holoptyhchius*), the concrescence of the basal parts of the unpaired fins passing through the same evolution as those of the paired fins. Represented in the surviving *Polypterus* ("*Bichir*" of the White Nile) and in the slender *Polypteroid Calamoicthys* (of Calabar), and in the extinct *Holoptychius*, *Undina*, *Diplurus* and *Coelancathus*.

II. *Actinopterygian*, the spine-finned Teleostomes. Fins supported by dermal rays; ancient fin support greatly reduced, implanted in the body wall. Includes *Chondrosteans* (Ganoids) and *Teleocephali* (Teleosts).

Among the fossil forms of the Crossopterygians *Gyroptychius* and *Osteolepis* from the Old Red Sandstone of Scotland are very similar to the early Dipnoans in the general appearance of the body. The tail is somewhat heterocercal and the dorsal fin is divided up into segments; but the teeth are numerous and arranged along the edges of the jaws instead of being reprerented by single plates. The entire body was covered by solid, bony scales the outside of which were covered by a layer of shining enamel. The anterior pair of the paired fins is approaching the condition in the Dipnoans, the archipterygium.

Holptychius, from the same locality and horizon as the last, is peculiar in that even at that early date it had developed the cycloidal, horny scales of the modern fishes, both the anterior and posterior paired fins are archipterygial in structure and the caudal fin has become nearly diphycercal by the fusion around the end of the body of the dorsal fins, the caudal and the anal. *Eusthenerpeton*, from the Devonian of Canada, is very similar to *Holoptychius*.

Diplurus, from Triassic of New Jersey, and *Undina*, from the Jurassic of England, present the last stage in the development Crossopterygians. They show an amount of specialization that indicates the extent to which the group had developed and the necessity for adaptation by its members to the most peculiar conditions to maintain an existence. *Undina* was short and very broad. The tail is especially broad and presented a very peculiar appearance, as the end of the spinal column extended beyond the broad psuedo-caudal fin formed by the posterior dorsal above and the anal below. The centra of the vertebræ are still unossified and the bases of the fins are reduced to single pieces of bone. In both this form and *Diplurus* the air bladder was ossified to a considerable extent so that it is preserved in the cavity of the body. *Diplurus* was greatly shortened in the body

by the enormous development of the psuedo-caudal fin, formed as in the case of *Undina* by the posterior dorsal above and the anal below, with the end of the vertebral column extending out beyond the two in a slender fin. The skull was relatively enormous and the jaws entirely edentulous.

Coelacanthus, from the Carboniferous of Ohio, is another of the highly-specialized Crossopterygians. The fins, scales, and general contour of the body is that of a modern bony fish, and it is only upon close examination that the fins were found to be of the archipterygial type and the caudal fin formed in the same way as the same fin in *Diplurus* and *Undina*.

The Actinopterygians are separated into two groups, the *Chondrosteans* and the *Teleocephali*. The first of these groups is very similar in many of its characters to the Crossopterygians, the most important difference and the one that marks the separation of the two greater groups is the structure of the fins. Instead of the lobate, or archipterygial type of fin with the well-developed basals and the symmetrically-arranged radials and fin rays, the basals have almost entirely disappeared and the fin has developed the monoserial structure, *i. e.*, the basal supports are confined to the most proximal part of the fin, and the rays are developed on one side only of the supports.[1] The skeleton is still cartilaginous and the scales are bony and covered with enamel.

Elonicthys, from the Permian of Europe, is a typical one of these forms, the body was somewhat elongate and the scales were narrow. *Eurynotus* from the Calciferous limestone of Scotland, *Cheirodus* from the Coal Measures of Scotland, and *Microdon* from the Jurassic of France, exhibit stages in the gradual development of a great vertical expansion of the body with an attendant shortening and flattening. In the last form there were developed flat crushing teeth instead of the sharp, conical form.

Aspidorhynchus, from the Jurassic of Solenhofen, was an elongate form much like the modern garpike in appearance

[1] See Fig. 3. Ichthyopterygium.

The body was protected by large enameled scales, and the head terminated in a long and sharp rostrum.

Palæoniscus is one the most important of the fossil *Chondrosteans*. It has a remarkable time range extending from the Palæozoic to the Mesozoic and developed a very large number of species. It is supposed to be the form that stands nearest to the ancestral type connecting the modern garpikes and the sturgeons.

These forms seem to have culminated in the modern sturgeons, in which the scales have almost entirely disappeared. In *Acipenser* a few rows of large dermal, enameled plates is all that is left, while in such forms as *Polyodon*, the spoon-billed catfish, the skin is entirely naked.

A second group of the *Chondrosteans*, developed mostly in the Mesozoic, had much more the appearance of the pure bony fish. The scales were small and rounded, and the fins are similar in shape and arrangement to some of the Teleocephali. The bones are calcified and the tail is nearly homocercal, but the vertebræ are still unossified and the notochord is prominent. The modern *Amia*, dogfish, is a surviving member of the group. Among the fossil forms are *Caturus*, *Megalurus*, and *Leptolepis*, from the Jurassic of Solenhofen. The first two of these are important in showing the formation of the vertebræ from the gradual development of bone in the centrum starting from the bases of the upper and the lower arches. In the first two of these forms the base of each arch is joined to a half-moon shaped element that is broad at the base and comes to a point at about the center of the centrum, the two together forming a ring that surrounds the notochord. In *Eurycormus*, from about the same horizon as the last, the same condition prevails in the vertebræ of the dorsal region, but in the tail the wedge-shaped half-moons are completed into bony rings and each vertebra is represented by two of these rings. (A condition that will be found of great interest in the consideration of the morphology of the vertebræ of certain of the amphibia.) The beginning of the process of forming the bony vertebræ by the growth of the

peripheral portion of the ring is seen in the more primitive forms, *Microdon* and *Pycnodus*. In the first of these the bases of the arches are expanded and terminate in rounded and flattened processes that cover the sides of the notochord to a considerable extent, but do not meet in the middle line. In the second form the bases of the arches are more expanded than in the first and the edges of the expanded portions are serrated so that they interlock both with the ones immediately before and behind them and with the one on the opposite side of the notochord.

There have been mentioned here, of course, only the forms that show to some extent the modifications and the lines of development along which the Ganoids traveled. The waters of the Mesozoic lakes and oceans were swarming with members of the group that presented almost as many varieties of structure and form as do the modern bony forms. Because of the strong, interlocking, enameled scales the whole body of the fish is commonly preserved, but the internal skeleton is much less commonly available, so that the most of the forms are known from characters of the scales and the position of the fins, both of which characters are, to a certain extent, unsatisfactory and unreliable.

The *Teleocephali*, the group generally known as the Teleosts, seem to have appeared at about the beginning of the Mesozoic time though it did not reach a great degree of development until near the close of that period and during the Tertiary time. The members of this group differ from the other forms of fishes in the complete calcification of the bones of the body and the nearly complete loss of the notochord by the development of the solid vertebræ which divides it up into intervertebral segments. The scales are horny and rounded, loosely attached to the skin and overlapping in the style of shingles. The fins are formed almost entirely by the dermal fin rays, the basals, and the radials being greatly reduced. Dean says, p. 167: "Fins are dermal structures, their ancient basal supports hardly to be distinguished; the primitive tail structure is so masked by

clustered and fused elements that its heterocercy is scarcely apparent. In short, the most widely modified conditions can be shown to exist in Teleosts in almost every structural character, as in gills, teeth, opercula, circulatory and urogenital organs, sensory structures and nervous system. They have evidently been competing keenly in the struggle for survival, for in every detail of form or structure the most varied conditions exist. In addition to these structural adaptations of the Teleosts, changes in coloration have been rendered possible by the transparency of their scales; and in their different families these changes have taken place often with striking results." It is impossible to go into the forms of the *Teleocephali*, for they are so many and varied that there is no outline even, that the limits of the purpose of this paper would permit. A study of the fossil Teleosts would be practically a study of the osteology of the recent forms.

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E. C. CASE.

EDITORIAL.

Editors Journal of Geology:

My attention has been called to a footnote, appended by one of your number, to a notice of mine, relating to Zirkelite, which note reads as follows: "The prior use of the name *Zirkelite* is certainly established, but it is a question how far a petrographer is justified in stigmatizing the name of a fellow-worker by attaching it to an indefinitely decomposed and ill-defined rock." (JOURNAL OF GEOLOGY, 1898, Vol. VI, p. 200.)

It would seem but common courtesy for another "fellow-worker" to ascertain the truth of his words before he takes advantage of his editorial position to publicly brand another as guilty of an action so low that it ought, if true, to forever ostracize him. I have differed on some points from Professor Zirkel, although in far many more I agree with him. It would seem that my writings prove that I have the courage to openly and honorably express my convictions, and that I do not have to resort to any such vile and disreputable tricks as that your associate plainly but falsely charges me with. I should despise myself if I did, and should expect to be shunned by all decent men. My warfare has ever been open, frank, and honorable, and I have never descended to personal spite and secret efforts to injure another. My contentions have been for what I honestly believed to be the truth, and when I have been shown to be, or found that I was, mistaken I have never hesitated to publicly acknowledge it. I have never taken difference of opinion as any cause for personal ill will, nor have I ever seen any reason why parties thus differing should not be the best of friends.

I gave the name Zirkelite to show my respect and esteem for the honored name of Zirkel, and to prove that, on my part

at least, there was nothing except the kindest of feelings towards him. Everyone who has worked in the field to any extent amongst the older basaltic rocks, ought to know that specimens of Zirkelite can be collected by the thousands, and that the rock is no more "indefinitely decomposed and ill defined" than are the great majority of the rocks designated by specific names, and that it is more common than many of them.

If my fellow-workers will give the name decent treatment, the rock will perpetuate the great name of Zirkel when his work and that of all of us shall have been nearly or quite forgotten in the bright light of future progress. I ask you, as gentlemen, to give my absolute and unqualified denial of the truth of your associate's statement just as wide and public a circulation as you have given to his outrageous and unjustifiable libel.

Very respectfully yours,

M. E. WADSWORTH.

MICHIGAN COLLEGE OF MINES,
Houghton, Mich., June 14, 1897.

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AN error was introduced in the scale of the map facing p. 250 of the last number of this JOURNAL in the photographic reduction for which the author was not at all responsible. The scale should have read: Horizontal, 1 inch = 3 miles. Vertical, 1 inch = 3000 feet.

Reviews.

VAN HISE'S "PRINCIPLES OF PRE-CAMBRIAN GEOLOGY."

For some years investigators and teachers of dynamic geology have needed a revision of the theories of Dana, Fisher, Reade, Dutton, Kelvin, and others, with reference to rock deformation. The publications of Van Hise are a contribution to such a revision, and other articles in preparation by him may probably summarize existing knowledge and current theory in a form, which will be a material advance.

By training, experience, and bent of mind, Van Hise is fitted for the task. As assistant and successor to Irving in the geologic investigation of the Lake Superior iron region, he has solved the most difficult problems of the older rocks. In microscopic petrography of the crystalline schists and allied formations he is a leading authority. In obscure stratigraphy and complex structural relations he has had much experience. His base of observation has been broadened to include all important districts from the Pacific to the Atlantic, and the classic localities of Europe.

The *Principles of Pre-Cambrian Geology* is a work intended "(1) to give a partial discussion of principles applicable to geological work among the pre-Cambrian rocks of North America, and (2) to give an historical account of the North American pre-Cambrian, and to point out the principles illustrated in the various regions."

In Part I the author discusses (1) movements of rock materials under deformation, (2) analysis of folds, (3) cleavage and fissility, (4) joints, (5) faults, (6) autoclastic rocks, (7) metamorphism of the sedimentary rocks, (8) metamorphism of the igneous rocks, (9) phenomena of stratigraphy.

Part II describes the facts of historical geology in general for the Archæan and Algonkian periods, and in particular for ten districts of the United States and Canada in which rocks of these ages occur. There is an appendix on " Flow and Fracture of Rocks as Related to

Structure," by Leander Miller Hoskins, who treats the subject by mathematical analysis.

In 1878 Heim published his discussion of "Umformung durch Bruch and Umformung ohne Bruch."[1] It was necessary less than twenty years ago that he should present an elaborate argument to show that without the action of any softening agent rocks might be deformed without fracture under appropriate mechanical conditions. He had seen and understood qualitatively the facts of folded strata. Van Hise carries the interpretation to quantitative expression in terms of pressure per square inch dependent on depth beneath the earth's surface. Following Heim, and going further than he did, Van Hise formulates three principles:

(1) Rocks under less weight than their ultimate strength when rapidly deformed are in the zone of fracture. (2) Since the boundary between the zone of fracture and the zone of flowage is at a different depth for two rocks of unequal strength, and for the same rock under different conditions of stress, there is a zone of combined fracture and flowage. (3) Rocks buried to such depth that the weight of the superincumbent strata exceeds their ultimate strength are in the zone of plasticity and flowage.

Under the assumption that rocks are porous, and that, therefore, interstitial spaces at a depth are sustained by a column of water extending to the surface, the author calculates, from formulas furnished by Hoskins, that no cavity can exist permanently in even the strongest rock at depths of 10,000 meters or more below the surface. As the development of cavities is a feature of fracturing, deformation with fracture is not possible below that depth. That zone in which deformation occurs without fracture is designated by Van Hise the zone of flowage.[2]

Since rocks vary in strength the depth of the zone of flowage beneath the surface is variable, and where rocks of unequal strengths are interbedded the harder may be in the zone of fracture, the softer in the zone of flowage. It follows that there is a broad zone of fracture

[1] Mechanismus der Gebirgsbildung, Vol. II, pp. 3–75.

[2] Since the paper reviewed was written, Van Hise has described much more fully the minute phenomena of the zone of flowage (Bull. G. S. A., Vol. IX, pp. 295–312). According to his recent conclusions, the deformation in this zone includes both microscopical granulation of the mineral particles and their recrystallization. Therefore in this zone he recognizes microscopic fractures and openings.

and flowage intermediate between an upper zone, in which all rocks fracture, and a lower zone in which all flow.

Gilbert and Dutton, as well as Heim, had anticipated the conclusions of Van Hise in the general recognition of a zone of fracture and a zone of flow, but Van Hise first describes clearly the phenomena of a zone of combined fracture and flow, with which geological observation of structure has chiefly to deal. He contributes also a closer analysis of the phenomena in the uppermost and lower zones. The development of autoclastic breccias, the production of folds by opening of radial joints due to fracture, the association of deformation by fracture and without fracture in the same zone, the adjustments of form by which strata yield to folding, the disappearance of folds in depth, and finally the phenomena in the zone of flowage, are clearly and critically discussed.

The analysis of folds is based upon a classification by de Margerie and Heim, published in 1888, but their ideas are amplified, and a comprehensive classification capable of including all types is developed by the author's recognition of the complex nature of folds. The author's primary classification divides flexures into simple, composite, and complex folds. Simple folds are single anticlines and synclines, which are subclassified in the usual manner as upright, overturned, or recumbent, and as symmetrical or unsymmetrical folds. But Van Hise recognizes that every fold of any magnitude is complicated by minor folds and each of these again by still smaller folds, and so on to microscopic plications of the *n*th order. When thus considered, the major fold may be termed composite. Composite folds of the first magnitude were described by Dana as geosynclines and geoanticlines, and these, as Van Hise points out, are due to combined action of gravity and lateral thrust. In the discussion of composite folds they are classified as normal and abnormal, and the basis of classification is the direction of convergence or divergence of the axial planes of the secondary folds. Thus in a normal anticlinorium the axial planes of the secondary folds converge downward and diverge upward, whereas in an abnormal anticlinorium the axial planes of the secondary folds converge upward and diverge downward. No exception can be taken to this classification as a matter of fact, but as a scheme adapted to instruction or to practical discussion it may not be generally useful, because the mind is speedily confused by the repetition of the terms of upward and downward convergence as applied to anticlinoria and

synclinoria of the various normal and abnormal types. Even one tolerably familiar with the aspects of folds must stop to draw a diagram before he can remember what the definition of a given type is.[1]

A definition of normal and abnormal folds, which may appear simpler, may be based on relative dips and depths of folds. It depends upon a law stated by Heim,[2] which is that from a normal anticline a stratum dips more steeply toward that syncline into which it descends to the greater depth. Thereon we may phrase the definition:

A normal fold is one in which the steeper dip is toward the deeper syncline of the same order, whereas an abnormal fold is one in which the steeper dip is toward the shallower syncline of the same order.

This definition has one advantage over that stated by Van Hise. It is related to the initial conditions which determine the positions of folds and their normal or abnormal development, whereas the axial planes are mathematical conceptions only, without actual existence. The relative depths of synclines and the steeper dips are frequently determined in the initial stages of development of folds, and persist as controlling conditions. In any littoral zone the steeper initial dip is usually from the land toward the sea. The resulting steeper dip after deformation holds a corresponding relation.[3]

Van Hise introduces a new use of the common term "monoclinal," in that he applies it to describe "that structure of a mountain mass in which the axial planes of all folds are inclined in the same direction." Discussing "monoclinal structure" he discriminates between overthrust folds and underthrust folds as follows, page 621:

"In monoclinal structure the force, and consequently the movement of the strata have usually been supposed to be more largely from one direction than from the other, and the axial planes of the folds have usually been regarded as dipping toward the force."

After reference to the ideas of H. D. Rogers, Van Hise continues, page 622:

[1] It has been suggested to me by Mr. L. C. Glenn that a general expression of Van Hise's law of normal folds may be phrased as follows: In a normal fold the axial planes converge centrically with reference to the arc which corresponds to the curvature of the anticlinorium or synclinorium. In an abnormal fold the axial planes converge eccentrically.

[2] Op. cit., pp. 231–233.

[3] Conditions of Appalachian Faulting, WILLIS and HAYES, Am. Jour. Sci., Vol. XLVI, October 1893.

"Folds thus produced by upward differential movement may be called 'overthrust folds.' The axial planes dip toward the effective stress, hence *overthrust folds are those in which the axial planes dip toward the force producing them.* While the development of overthrust folds is the general law, it may not infrequently happen that under favorable conditions the beds or formations may be thrust forward and downward. The folds thus produced by downward differential movement may be called 'underthrust folds.' The axial planes dip away from the effective stress, hence *underthrust folds are those in which the axial planes dip away from the force producing them.*"

The idea of Rogers that deformation proceeded by a wavelike motion, which, in the case of the Appalachians, emanated from the Atlantic region, is firmly fixed in geology without being sufficiently justified by facts. Appalachian structure in many districts presents a monoclinal inclination toward the southeast. If it be overthrust, the effective force operated from that direction. If it be underthrust, the effective force acted from the northwest. There is nothing in the monoclinal relations of folds which will determine that alternative. Theoretically, the geologist is at liberty to infer overthrust in preference to underthrust or *vice versa*, but an hypothesis of the origin of force based upon that inference is of no value. The analysis given by Van Hise leads him to the conclusion that the monoclinal folds and cleavage which prevail in the crystalline areas of the Appalachians are due to an effective force from the southeast, but that conclusion cannot be considered as demonstrated. Indeed, other geologists approaching the problem from a different point of view are justified in reaching the reversed conclusion.

It may be suggested that compression, which causes strata to fold, is a force of gradual accumulation, that is, of such slow growth that the pressure is transmitted through a rock-mass of indefinite extent until movement ensues. Such movement may probably begin at a point determined by local conditions, and may continue in a direction determined by the least resistance either as an overthrust or an under-thrust. In that view the more effective force is simply that which is opposed to the less effective resistance, and the hypothesis of a wave-like influence emanating from a distant source is unnecessary.

Complex folds are defined by Van Hise as those canoes, basins, and domes which result where two sets of folds intersect each other.

The two sets of folds may be produced simultaneously or at distinct epochs by two or more thrusts in diagonal directions or at right angles. Any two diverse thrusts inclined to each other may be resolved into two forces at right angles, which will produce complex folds; if, however, the divergence of the two thrusts is moderate, their effect may be combined to produce a simple system of parallel folds.

Of the two thrusts producing complex folds, one is usually the major thrust, the other the minor thrust, and the system of composite folds to which one or the other gives rise may be described accordingly as the major or the minor system. The length of canoes is proportioned to the difference in power between the major and minor thrusts. If the major thrust greatly exceeds the minor, the complex folds will be long, narrow, and parallel; if the two thrusts are nearly equal the folds will be domes and basins.

As an example of complex folds Van Hise refers to the Appalachian region. The reference, perhaps, requires qualification to modify its general application to the whole province. Districts of New England and North Carolina do exhibit complex folds which are markedly developed in the direction of the minor as well as of the major thrust, but in the Appalachian Valley region from New York to Alabama the folding scarcely appears to be complex. Van Hise cites the undulatory pitch of the axes as evidence of a pressure from northeast to southwest. The pitch is to some degree due to variations of initial dip and the depression of synclines in folding. There is no crenulation of the major strikes such as might be expected to result from a transverse thrust. If this zone of typical Appalachian structure shall be shown to be complex in the sense in which Van Hise defines the term, there will be good reason to assume that complex folding is the general rule. This may probably be so.

Van Hise's extensive experience in the study of complex structure enables him to suggest practical methods as to the manner of determining whether the rocks of the district are complexly folded and in what manner. These suggestions relate to the manner of making certain necessary observations, which he sums up as follows:

1. "Determine the strike and dip of the strata at the given point. These give the resultant position of the strata as tilted by the force. of folding in both directions."

2. "Determine the direction of the pitch of the axes of the major folds. The first is the direction of dip, and the second is the amount

of dip of the minor or cross folds. The average strike is therefore determined."

3. "Determine the direction and pitch of the axes of the minor folds. The first is the direction of dip, and the second the amount of dip of the major folds. The average strike is therefore also determined."

Van Hise correctly observes that of these three observations the first is the only one ordinarily taken, and it is the one of least importance in regions of close complex folding. It becomes obvious in considering his practical suggestions that a thorough knowledge of the physiography of the region and the relation of relief to structure is quite as important for the solution of complex folds as is a knowledge of the rocks.

Concluding the section relating to folding, Van Hise considers the value of differential folding as an evidence of unconformity, when not sustained by other phenomena. A discordance in the flexures of two adjacent formations is only to be absolutely relied upon as evidence of unconformity when the structural discordance is so marked that the earlier series exhibits a relatively complex structure as compared with that of the later series.

In Section III Van Hise considers cleavage. He grasps hypotheses of the origin of cleavage advanced by other geologists from Phillips to Becker, discriminates between them, amplifies their basis of fact by his own extensive observations of the crystalline schists, and states those conclusions which he finds valid. He defines *cleavage* in a strict sense "as a capacity present in some rocks to break in certain directions more easily than in others." This use of the term is that in which it is applied to minerals. He distinguishes fissility as a phenomenon secondary to cleavage, fissility being "a structure in some rocks by virtue of which they are already separated into parallel laminæ in a state of nature."

Citing microscopical study of cleavable slates and schists, Van Hise concludes (page 635) that:

"Rock cleavage is due to the arrangement of the mineral particles with their longer diameters or readiest cleavage, or both, in a common direction, and that this arrangement is caused, first, and most important, by parallel development of new minerals; second, by the flattening and parallel rotation of old and new mineral particles; and third, and of least importance, by the rotation into approximately parallel positions of random original particles."

From these observations follows the inference that cleavage develops in a plane normal to the pressure. The grounds for this inference are discussed at some length and the author's opinion is finally stated (page 639):

"I therefore conclude from analysis, from experiments upon viscous and plastic bodies, from observations in the field, and from studies with the microscope, that I am justified in the statement that the secondary structure of a rock which is deformed by plastic flow develops in the plane normal to the greatest pressure, and that this structure is true cleavage."

From the observed parallelism to the inferred normal relation to pressure is a step in hypothesis. To this extent the conclusion falls short of demonstration, but it is in accord with the opinions of eminent students on cleavage, and is supported by mathematical analysts, with one marked exception. The exception is Mr. Geo. F. Becker.

It has been maintained by Becker that cleavage always develops in two shearing planes at angles to the pressure. His method of arriving at this conclusion may best be indicated by a quotation from his article:[1]

"In the following pages the attempt will be made to develop all the manifestations of uniform or homogeneous finite strain in rock-masses regarded as isotropic, exhibiting viscosity and capable of flow, which can be elucidated without assuming a law connecting stress and strain. For this purpose finite strain must first be discussed by itself; then it must be considered just how far the relations of stresses are capable of coördination with those of strain. The influence of viscosity and solid flow must next be shown. Readers willing to assume that these subjects have been logically treated will probably skip them and proceed to the geological applications which follow. Finally, the results will be compared with actually observed phenomena and with the experiments which several investigators have made on slaty structure."

The method followed by Van Hise is that of induction from the facts, whereas Becker pursues that of deduction from general principles. Van Hise does not deny the validity of Becker's reasoning nor its general application. He describes the development of fissility and jointing in the zone of fracture as in accordance with Becker's view. But he con-

[1] Finite Homogeneous Strain, Flow, and Rupture of Rocks, by G. F. BECKER, Geol. Soc. Am., Vol. LV, 1891, p. 16.

cludes that in the zone of flow another process is effective to product cleavage; namely, special orientation of minerals and particles.

Fissility is defined by Van Hise as a parting of a rock along shearing planes, which corresponds with the structure described by Becker as cleavage. It is obvious that a capacity to part in a certain plane (Van Hise's cleavage) may often coincide with an actual parting developed later. If the capacity to part be a structure developed in the deep zone of flow, it is most probable that the actual parting should be developed in rising through the zone of fracture, as any rock mass must to become accessible to our observation. Hence arises the opportunity for confusion of the two structures, according to Van Hise, but discriminating the one from the other he concludes that: "Fissility developing in the shearing planes is usually secondary to cleavage which developed in the normal planes."

The relations of cleavage and fissility to bedding and to folds are discussed at length, and the value of these structures as criteria for determining unconformities are stated and limited.

With reference to joints Van Hise's discussion is along lines logically consistent with his views of folding and also of fissility. Tension joints may be produced radially to the curvature of folds; this phenomenon he rightly considers important as a means of accommodation to curvature in the zone of fracture. Compression joints develop in shearing planes, usually in two directions, and when associated with simple folds generally parallel to the strike. When folding is complex different sets of shearing plains may correspond to strike-joints and dip-joints, but the association of three or more joint systems may probably be the result of several orogenic movements.

Faults also are classified as tension faults and compression faults, but recognizing the dominant influence of gravity or of thrust respectively, Van Hise well prefers to distinguish them as "gravity" faults and "thrust" faults. The former is equivalent to the old term "normal," the latter to the inaccurate designation "reversed" fault.

In discussing the relation of faults to folds it is stated that under moderate load thrust faults may result as clean cut fractures, whereas under greater load they may be associated with overfolds, and at still greater depths overfolds may develop without thrust faults.

"This statement might be well supplemented by the further explanation that folds may give place to thrusts on diagonal planes in the deep zone of flowage. Two conditions are essential to folding;

first, that the stratum shall be sufficiently rigid to transmit a maximum stress in a definite direction; and second, that movement on bedding planes shall afford a means to adjustment to curvature. It is an open question how far these conditions are effective in a deep zone of flow. In the opinion of the reviewer neither of them exercises a dominant influence. Distinctions of stratification may become insignificant under excessive pressure, and great friction on bedding planes may prevent accommodation, and the mass may be deformed by dislocation in the diagonal planes. This is illustrated in model J, Plate XCIII, stages *f* to *k*, "Mechanics of Appalachian Structure." The accommodation of the soft material to shortening in one direction and elongation in another is there accomplished by the reciprocal displacement of wedges, which are defined by planes diagonal to the applied force. This explanation is briefly suggested by Van Hise in a subsequent paragraph on the depth of the zone affected by faults, but he fails to emphasize the idea that while thrusts developed in the zone of fracture pass into folds below, folds in turn may be replaced by thrusts at still greater depths. The relation is important."

Comparing the effect of few great structures with that of numerous small ones, Van Hise concludes:

"The average deformation of a region may be the same whether it be by a few great faults with little or no fissility, by more frequent lesser faults with or without fissility, by faults and overfolds with or without both cleavage and fissility, or by folding with or without faults and cleavage; also that there is every gradation between faulting and fissility, and probably every gradation between faulting and cleavage."

In Section VI, Van Hise discusses dynamic breccias and pseudo conglomerates under the generic term of "autoclastic" rocks, which was first used by H. L. Smyth. The development of autoclastic rocks is limited to the zone of fracture and they are not of common occurrence in strata younger than the Cambrian. But where they occur in rocks which have undergone repeated disturbances the resulting dynamic breccia may so resemble a basal conglomerate as to lead to an erroneous inference of unconformity. In the discussion of these cases Van Hise inadvertently illustrates with what remarkable care and patience the geologic study of the Marquette district has been pursued.

Metamorphism is treated in sections VII and VIII, with the purpose "briefly to sketch a few of the more important processes which have

affected large areas of the pre-Cambrian rocks of North America." The author recognizes pressure, heat and chemical affinity as the prominent forces producing metamorphism. When pressure is resisted by rigidity, *i. e.*, produces only molecular motion, the result is static metamorphism; when pressure passes into mass motion the result is dynamic metamorphism. The chief processes considered are consolidation, welding, cementation, injection, metasomatism, and mashing.

In discussing cementation and injection the author takes up the origin of pegmatites and says:

"It seems to me that to adequately explain all the facts of pegmatization described in various regions of the world, we must conclude that all three processes have been at work—in some cases igneous injection, in some cases aqueo-igneous action, and in other cases pure-water cementation, and in still others combinations of two or all of these processes. It is further believed that there may be no sharp separation, but, on the contrary, all gradations between the three—that is, it is thought highly probable that under sufficient pressure and at a high temperature there are all gradations between heated waters containing mineral material in solution and a magma containing water in solution. In other words, under proper conditions water and liquid rock are miscible in all proportions. From the water solutions true impregnation or cementation would take place; from the rock solutions, true injection. Pegmatization may comprise these and the intermediate processes."

Metasomatism is described with reference to (1) "alteration of original mineral particles, (2) minerals produced by alterations, and (3) texture of rocks produced." The brief statement of facts familiar to petrographers suggests also breader aspects of comparative petrology.

"Mashing is a term here introduced with a specific meaning. It is used to designate by a single word that complex process which involves shortening without change of volume, or simple shearing, or a combination of the two. Mashing implies all the other special processes of metamorphism."

Having thus considered in general the processes of metamorphism, Van Hise classifies metamorphic sedimentary rocks according to those processes which have been particularly effective in the development of each class. The enumeration of rock types in relation to conditions affecting their development is particularly valuable.

Metamorphic igneous rocks are treated separately, though briefly, but the means of discriminating between originally sedimentary and originally igneous rocks are discussed with the insight due to broad observation. The difficulties of discrimination are suggested in the following statement:

"It has been seen on previous pages that a large number of kinds of schists and gneisses may be produced by the metamorphism of sedimentary rocks; also it has been shown that similar crystalline schists may be derived from igneous rocks. It is further certain that a schist or gneiss may be derived partly from sedimentary and partly from igneous rocks. For instance, a metamorphosed fissile sedimentary rock, such as mica-schist or mica-gneiss, may be injected in a complicated way parallel to the planes of schistosity, and thus produce a banded gneiss, part of which is igneous and part of which is sedimentary. The rock may be predominantly of either one of these materials. If the injected sedimentary rock be subsequently folded, this will produce differential movements parallel to the banding, and the igneous and aqueous bands may be merged into one another and have structures so similar that it is impossible to determine what part of the rock is igneous and what part aqueous. The Manhattan schists of southeastern New York, and especially near Long Island Sound, are a perfect illustration of a gneiss produced by the extreme metamorphism of a sedimentary schist and the subsequent parallel and cross injection of granitic material.

"From the foregoing it is clear that an inseparable schist or gneiss formation may be produced from altered intrusive rocks, from altered lavas, from altered tuffs, from altered sediments, and from any possible combination of two or more of these.

"Doubtless, in regions in which the gneisses are of a very complex character, a number of the processes mentioned in the previous pages, and possibly others unknown, must be united in order to explain all of the phenomena."

Stratigraphy, *i. e.*, the sequence of formations, is deduced for pre-Cambrian rocks from observations of the phenomena of structure and metamorphism and other relations in detail. It thus becomes an inference instead of being a primary fact of observation, as it may be in rocks which are less disturbed. Van Hise, therefore, gives stratigraphy a logical position at the close of his discussion of principles. The evidences of stratification which are obvious in unaltered series

may be so obscured in older rocks as to be determinable only by the closest observation. Hence, bedding, ripple marks, basal conglomerates, and phenomena indicating unconformity afford material for extended consideration.

This review would be made too long by detailed references to the second part of the "Principles," which treats of the historical geology of the pre-Cambrian time. The discussion is arranged according to districts and for each district the principle most saliently illustrated is emphasized. This part of the book constitutes a valuable summary of existing knowledge and a convenient and reliable reference.

The style of the author is the expression of complete knowledge of his subject, combined with exuberance of thought. Another great writer, whose works are characterized by brilliancy and clearness, recently said: "When I undertake to write a book I endeavor first to see what I can exclude from it, and after the process of rigid exclusion I carefully arrange the surviving ideas even to the order of paragraphs before I write." The thoughts which rush upon Van Hise are related in so many directions that many associations of the idea seek expression at once. His book would be easier to read and not necessarily less accurate, if the thought were stripped. The logical analysis is consistently carried out for all the major headings, but it is not adequately extended to the paragraphs and sentences. Nevertheless, a thorough study of the work leaves a profound impression of the earnest purpose with which it has been conceived and of its value as a contribution to one of the most difficult branches of geologic science.

BAILEY WILLIS.

Topographic Atlas of the United States. Physiographic Types by HENRY GANNETT. Washington: U. S. Geological Survey, 1898.

The enlightened policy adopted by our national Geological Survey of encouraging as wide a use as possible of the material gathered at great expense receives a new and welcome illustration in the publication of the first folio of the above named series. It presents ten maps as "illustrations of some of the simplest and most characteristic types of topography to be found in those parts of the United States which have been thus far mapped. Succeeding folios will illustrate more complex forms." The origin of the atlas was in a proposition of the

director of the survey to publish "an educational series of folios, for use wherever geography is taught in high schools, academies and colleges," authority for such publication having been granted by Congress in an act approved March 2, 1895.

The following titles represent the contents of this first folio: A region in youth: Fargo, North Dakota-Minnesota. A region in maturity: Charleston, W. Va. A region in old age: Caldwell, Kan. A rejuvenated region: Palmyra, Va. A young volcanic mountain: Mt. Shasta, Cal. Moraines: Eagle, Wis. Drumlins: Sun Prairie, Wis. River Flood Plains: Donaldsonville, La. A fiord coast: Boothbay, Me. A barrier-beach coast: Atlantic City, N. J. It may well be claimed that no more important, useful, or interesting series of maps could be selected for the elementary exposition of physiographic types.

It must be most encouraging to teachers of geography to find so efficient an ally as this series of folios will prove. Such a publication gives an authoritative stamp, such as has not yet been received in any other country, to the methods of modern physiographic description. It recognizes the essential importance of stage of dissection and movement with respect to baselevel, as a means, not merely of explaining the past history of a region, but of describing its present form. Withal, the text is written in a clear and simple style, certainly within the reach of even those teachers of other subjects upon whom the unexpected responsibility of having to teach geography so often falls. The few technical terms that are employed are fully explained. The relation of form to conditions of settlement and movement are touched upon. The later numbers of the series will be awaited with much interest.

Where so much is good, it gives regret to find the text of one map open to adverse criticism. The account of the Booth Bay sheet needs revision regarding glacial action. The region is described as having been for a long time "subjected to aqueous erosion, which brought it to a condition of old age with gently flowing streams, smooth slopes, and rounded divides." Upon such a surface advanced the Great Northern Glacier, and proceeded to modify it. It is difficult for the reader of this part of the text to avoid concluding that when southern Maine was thus "planed down by aqueous erosion," it was about as flat as the plains of Kansas—the type of old age—and that its marked relief today is the result of glacial erosion. There is, on the contrary, good reason for believing that since the greater part of New England was

brought to a condition of old age, it has been rejuvenated and more maturely dissected than the Piedmont upland of Virginia, the type of renewed dissection in a second cycle. The ice-sheet therefore advanced over a region of distinct hills and valleys, not over a peneplain. The implication that the ice-sheet was an effective agent of destruction is confirmed on reading that the traces of glacial action "here consist mainly of features of erosion. But little matter was deposited by it, that little consisting of what is known as 'erratics,' or granite bowlders, which are scattered freely over the country. . . . . A great deal of erosion, however, was done by the ice-sheet. It searched out very keenly the soft spots in the granite surface of the country and scoured them away, leaving depressions and, between such depressions, rounded hills of granite. . . . . All of the soil or disintegrated rock was scraped away, leaving the granite bare; hence it is that the soil covering of southern Maine is very thin, for it has been derived mainly from the disintegration of rocks since the passing of the glacier." Apart from the implication that the hills today result from the glacial excavation of depressions between them, and from the implication that granite is the only kind of rock in this region whose linear ridges and fiords give so strong an indication of foliated or stratified structures, it is unfortunate that the common veneer of till, the relatively plentiful deposits of washed gravel and sand, and the important cover of marine clays in the valley floors of southern Maine should pass unnoticed. The farmers of that region very rarely depend on soil of postglacial weathering. The rocky ridges with a thin soil, partly of glacial drift, partly of postglacial weathering, are left in uncultivated forests and woodlots.

It is further to be regretted that, after showing by the first four types that time is an important element in geographical description, no sufficient mention is made of the element of time in connection with the two examples of shore-line features. It is of course recognized that the irregular coast line of Maine is a result of the partial submergence of a rugged land; but no consideration is given to the evidence that the submergence is recent; so recent that wave action has not yet cut back the headlands, and that river action has not yet filled up the bay heads. Hence the account of shore lines is not homologous with that of land surfaces, in which the stage of advance reached by destructive processes is carefully considered. The opportunity for teaching an important principle in the evolution of shore lines is thus lost.

W. M. DAVIS.

Volcanoes of North America : A reading lesson for students of Geography and Geology. By ISRAEL C. RUSSELL. The Macmillan Company, New York, 1897.

The object of this book is plainly stated by the author in the introduction —"It is to the character and history of this vast volcanic belt, reaching from the tropical shores of Costa Rica to the western extremity of the bleak and inhospitable Aleutian Islands, that the attention of students of geology and geography is here invited. The object of this book is to make clear the principal features of volcanoes in general, and to place in the hands of students a concise account of its leading facts thus far discovered concerning the physical features of North America which can be traced directly to the influence of volcanic action." Its title indicates that it is not intended to be a thorough treatise on the subject, but rather a readable account of the leading features. It will undoubtedly prove satisfactory to those who read it with this understanding. It has gathered together in an attractive form many scattered descriptions of the volcanoes and volcanic mountains of North America, and has placed the student in the way of finding the original accounts. It will excite interest in the volcanic phenomena to be found on this continent and will perform a helpful mission. The arrangement of the material is good and the interest of the reader well sustained by the general style. The illustrations are valuable and attractive.

There are, however, numerous evidences of carelessness in the work which are to be regretted. The section on the Characteristics of Igneous Rocks is open to severe criticism. Its definitions are crude and misleading, and incorrect arguments are presented in several instances. The section should be carefully revised.

The effort to connect the active volcanoes of Central America with those of the Aleutian islands, as though they constituted one chain, is not justified by the facts; the former being much more closely connected with those of the Andes, and the Alaskan volcanoes with those of the Japanese islands.

The descriptions of the volcanoes within the United States are somewhat unsatisfactory since they bear little relation to their relative importance. Considerable space is devoted to detailed descriptions of very insignificant craters in Utah and Nevada, and to the comparatively small volcanoes near Mono Lake, Nev., while much less is given to that of the great mountains, Shasta, Rainier, and other volcanoes of

the Pacific Coast. And no mention whatever is made of the volcanic region of the Yellowstone National Park, a region not only characterized by great diversity of volcanic phenomena, where the influence of volcanic action on the physical features of the region is most marked, but one that is being constantly visited by students and tourists.

The chapter devoted to the theories of volcanic action is good in the main for an elementary treatment of the subject. But some of the reasoning is obscure, especially that with reference to the behavior of absorbed vapors, and the question of their presence or absence from deep-seated and surface rocks. The effort to minimize the effect of steam upon the eruption of lava appears to have been carried too far.

It is greatly to be regretted that defects such as these exist in a book that has so many excellent features to recommend it.

J. P. I.

Revised Text-Book of Geology. By JAMES D. DANA. Edited by WILLIAM NORTH RICE. American Book Company, New York.

The earlier editions of this work are so well known that interest in the present edition is concerned chiefly with the nature of the revision. This had been begun by Professor Dana a short time before his death, but little progress had been made. By request, his former pupil, Dr. William North Rice, completed the work. His aim has been to retain the distinctive characteristics of the book so far as possible and, while bringing it down to the present time as regards its facts, to preserve the known opinions of its author. The editor has endeavored to subordinate his own views to those of the original author, although on certain points, as for example, geographic and climatic oscillations of the Quaternary era, he would have preferred a somewhat different expression. The general plan of arrangement remains unchanged and the omissions about counterbalance the introductions. The zoölogical and botanical classifications previously used were judged to be obsolete and the schemes followed in a majority of the recent manuals of zoölogy and botany were substituted. The theory of evolution finds fuller recognition than in the previous editions. In the treatment of metamorphism the text is considerably modified, especially with reference to the dynamic phases and to the foliated structure of igneous rocks. Otherwise the book presents essentially

the views of science held by the distinguished author in his later years. In the very delicate task of eliminating such errors as the progress of science has developed, and at the same time of deferring almost reverentially to the opinion of the author, Dr. Rice appears to have attained a high degree of success, although some further eliminations of opinions and interpretations which, though not absolutely abandoned by all geologists, have been practically overthrown, might have added value to the work. T. C. C.

Fossil Plants for Students of Botany and Geology, Vol. I, 450 pp., with illustrations. By A. C. SEWARD, University Press, Cambridge, Eng., 1898.

Botanists and geologists both are bound to welcome Professor Seward's work on Fossil Plants, the first volume of which has recently appeared. This book forms one of the familiar Cambridge Natural Science Manuals, and is rather more extensive than the others. It is safe to say that no general work on palæobotany had previously appeared in English that was satisfactory to both botanists and geologists, and very few that were satisfactory to either. Hence it is a pleasure to read in the preface that this book is intended for both botanists and geologists, and thus has to be adapted to both non-geologists and non-botanists, since it is unfortunately true that neither class, as a rule, appreciates the standpoint of the other. The first chapter contains a brief historical sketch of palæobotany in which the author gives special credit to Brongniart and Williamson. Chapter ii gives the relation of the subject to botany and geology. Professor Seward tells how palæobotany has been buffeted about by the geologist and the botanist, the one culling out facts relating to correlation of strata, the other caring only for facts which give hints as to phylogeny and evolution. He pleads for the recognition of palæobotany as a science of and for itself, with its own peculiar problems, viz., the determination of the historical succession of plants in geological time; the delineation of the actual evolution of the plant kingdom, giving light on phylogenetic mysteries; the presentation of the various floral areas of the past, leading up to an explanation of the distribution of plants in the present day; conclusions as to climatic and other conditions in geological time as revealed by the occurrence of certain peculiar plant types and

by anatomical adaptations to environment. The third chapter gives the leading facts of geological history, and is designed for botanical readers. The next chapter discusses the various methods for the preservation of plants as fossils; structure unmodified, as in fossil soils and forests; carbonization; incrustation, as travertine; casts; petrifactions. The relative rarity of plant fossils is due to their soft structure and land habitats. Chapter v is exceedingly interesting and valuable, as it demonstrates the enormous difficulties and sources of error, such as (1) the danger of depending too much on external resemblances, since many forms from algæ up to seed plants may look alike even in modern forms, much more in fossils; (2) fragmental preservation—this is much more common than in animal fossils, and also leads to much more error, since a plant often can be identified only in fruit; (3) decorticated trunk and pith cylinders; (4) resemblance to animals or animal tracks and mineral deposits.

After a chapter on nomenclature, the author takes up the plants by groups. In this first volume he treats only of the Thallophytes, Bryophytes, and some Pteridophytes. Among the algæ there is an abundance of undoubted fossil blue-green algæ, forming deposits of travertine and possibly oölite. Professor Seward thinks that similar forms probably represented the first life of the Algonkian. Because of their siliceous tests there are vast deposits of diatoms, mainly from the Cretaceous on. Of the larger marine algæ those forms are especially preserved which are covered during life by calcareous incrustations, especially the corallines. Many plants of all kinds and many mineral deposits, rill marks, and animal tracks have been referred to the algæ, and especially to the fucoids. Among fungi there are abundant evidences of fossil bacteria, but the higher forms are rare, though found in the Carboniferous and Tertiary. The liverworts and mosses are poorly preserved and difficult to identify. Of the Pteridophytes, the author considers in this volume only the equisetales and sphenophyllales. Both of these groups are abundantly preserved and well known. At the close of the volume is an excellent bibliography.

This work of Seward's has at least three features to commend it that are by no means common to all books on palæobotany. It is extremely cautious in its statements; many forms commonly described are either classified tentatively or omitted altogether. There are not so many startling allusions to high-grade plants in the early ages, but there are more real facts on which to base safe conclusions. Another

valuable feature of the book is that important facts have been culled out from a mass of unimportant material; and by no means least in its commendable qualities is the fact that it is actually readable; even the botanical or geological layman may enjoy it if he cares for such things at all. Everyone who reads the first volume will anxiously await the appearance of the second.

HENRY C. COWLES.

Northward Over the "Great Ice": A Narrative of Life and Work along the Shores and upon the Interior Ice-Cap of Northern Greenland in the years 1886 and 1891–1897. By ROBERT E. PEARY. 2 vols. Illustrated. Frederick A. Stokes Co., New York. 1898.

In these two volumes, embracing nearly 1200 pages, Lieutenant Peary has given a graphic account of his entire Arctic work. The story begins with a reconnaissance of the inland ice of Greenland in 1886. The objects and results of this reconnaissance he summarizes as follows:

Objects. — To gain a practical knowledge of the obstacles and ice conditions of the interior of Greenland; to put to the test of actual use certain methods and details of equipment; to make such scientific observations as may be practicable; and to push into the interior as far as possible. (Paper read before National Academy of Sciences at Washington, D. C., April 23, 1886.)

Results. — Attainment of greater elevation tban ever before reached on the inland ice; penetration a greater distance than any white man previously; attainment for first time of the real interior plateau of unchanging snow; determination of ruling characteristics of the inland ice from border to interior (see article in *Bulletin Am. Geog. Soc.*, No. 3, 1887, pp. 286–288); securing an invaluable fund of definite practical knowledge and experience of actual ice-cap conditions and necessary equipment, as well as practical knowledge of Arctic navigation and a familiarity with a considerable extent of the Arctic coasts; inception of ideas of pronounced future value, as odometer, sails, etc. The following deductions: Attacks upon the inland ice should be made at a point as far above level of sea as possible, and where the presence of large and rapidly discharging glaciers indicates a rapid ascent to high elevations in close proximity to coast; party should be *small*, and thoroughly accustomed to snowshoes and ski; surface of inland ice offers imperial highway to east coast, and, in case the ice-cap is coëxtensive with the

land, to the northern terminus of Greenland. Proposal of the following prophetic routes: From base of Noursoak Peninsula to head of Franz Joseph Fjord and return; from Whale Sound to northern terminus of Greenland or intersection of ice-cap with east coast — this route the key to the Greenland problem; from Disco Bay to Cape Dan.

The remainder of Vol. I is occupied by the story of the North Greenland expedition of 1891–2. Most of our readers are doubtless familiar with this famous trip across the northern portion of the great ice-cap, but still they will read this authoritative statement by the explorer himself with fresh interest and satisfaction. The author summarizes the objects and results of this expedition as follows:

Objects. — Determination of the northern limit of Greenland overland; the possible discovery of the most practicable route to the Pole; the study of the Whale Sound Eskimos; the securing of geographical and meteorological data.

Results. — The determination of the northern extension and the insularity of Greenland, and the delineation of the northern extension of the greater interior ice-cap; the discovery of detached ice-free land-masses of less extent to the northward; the determination of the rapid convergence of the Greenland shores above the seventy-eighth parallel; the observation of the relief of an exceptionally large area of the inland ice; the delineation of the unknown shores of Inglefield Gulf; and the imperfectly known shores of Whale and Murchison sounds; the discovery of a large number of glaciers of the first magnitude; the first complete and accurate recorded information of the peculiar and isolated tribe of Arctic Highlanders (Dr. Cook); complete and painstaking meteorologlcal and tidal observations (Verhoeff); sledge journey, which is unique in respect to the distance covered by two men without a cache from beginning to end, and in respect to the effectiveness with which those men were able to handle a large team of Eskimo dogs; corroboration of the opinion advanced that the inland ice offered an "imperial highway."

Vol. II opens with a narrative of the expedition of 1893–4, which is memorable on account of the great equinoctial storm encountered, that appears to have been without a recorded parallel even in that land of terrific gales, and that proved disastrous to the undertaking. Among the subsidiary narratives of special interest are the stories of the discovery of the great Cape York meteorite by Peary and the reconnaissance of Melville Bay by Astrup. In this part are also included a summary of the valuable meteorological observations of Baldwin. Then follows an account of the visitation of the *Falcon*,

the return of the larger part of the party, the voyages of the fall and the winter, and the story of the third winter passed in the high north.

The climax of sympathetic interest is reached when Peary comes to tell of his second crossing of the ice-cap in the face of unusual difficulties, and of the scant margin by which he escaped several threatened sources of disaster. The objects and results of the expeditions of 1893–5 are summarized as follows:

Objects.— The delimitation of the detached lands lying north of main Greenland; the filling in of the remaining gaps in the northern and northeastern coast line of Greenland; in the event of favorable conditions, an attempt upon the Pole; the completion of the detail survey of the Whale Sound region; continuation of the studies of the Smith Sound Eskimos; the discovery of the "Iron Mountain."

Results.— The crossing of the inland ice-cap of north Greenland under a most serious handicap of insufficient provisions; the completion of the detail survey of Whale Sound; large accessions of material and information in connection with the Smith Sound Eskimos; the discovery of the "Iron Mountain" or Cape York "Saviksue," and the bringing home of two of those interesting meteorites.

The work is completed by the narrative of the two summer voyages made in 1896 and 1897, whose chief object was the bringing home of the great Cape York meteorite, which was successfully accomplished by the latter expedition.

The work is written in clear and graphic style, and the story is followed with ease and satisfaction by the reader. The narrative moves forward at a steady and rather rapid pace, and is unusually free from tedious passages. The size of the work is not due to needless deployment of details or the introduction of much subjective matter. It is merely an expression of the great amount of work which Lieutenant Peary has done. His aim has been, as stated in the preface, to condense and to avoid all padding. In the main he has avoided exploiting his feelings, a practice quite too much the fashion with Arctic explorers. When he has given them expression it has usually been on occasions that specially invited it, and then with brevity and good taste.

The scientific reader will of course wish that the natural phenomena of that wonderful region had been set forth with greater detail and with more special reference to their scientific bearings, but this would doubtless have been less acceptable to the great mass of readers

for whom the work was written. There is a hint that the scientific results will be specially treated in some later work. The scientist will, however, find this work rich in phenomena of the highest interest, not less in the illustrations than in the text. No work on the great white north has ever been so amply and so accurately illustrated as this. The 800 photographic illustrations tell their own story. Lieutenant Peary was as fortunate as he was industrious in making an unassailable photographic record of his explorations. Neither storms, dangers, nor stress of circumstances seem to have stopped the work of his ever-present kodak. The mechanical execution of the half-tones, while in the main fair, yet leaves something to be desired. Their extreme value would have warranted the use of the best available paper and of the utmost skill in printing. Their execution is sufficiently good, however, to lend an inestimable value and interest to the text.

T. C. C.

United States Geologic Atlas, Folio 41, Sonora, California. 1897.

The folio consists of seven pages of text signed by H. W. Turner and F. L. Ransome, geologists, a topographic map of the district, an historical geology sheet, an economic geology sheet, and a structure section sheet.

The quadrangle represented in this folio lies between the parallels of 37° 30′ and 38° north latitude, and meridians of 120° and 120° 30′ west longitude. It comprises a portion of the western slope of the central Sierra Nevada, chiefly in the foothill region. The quadrangle covers portions of Tuolumne and Mariposa counties, including, also, corners of the valley counties of Stanislaus and Merced. The area is drained chiefly by the Tuolumne and Merced rivers.

The formations are divided into two main groups: The bedrock series, and the superjacent series. The bedrock series is composed of Juratrias and Palæozoic sediments with interbedded lavas and tuffs, and a series of old igneous rocks, chiefly quartz-diorites, serpentine derived from peridotite, and porphyries. The Juratrias rocks are chiefly clay-slates with some sandstone, and are called the Mariposa formation, since the characteristic Jurassic fossils of the formation were first found in Mariposa county. The Mariposa formation is represented by three distinct belts of slates, the most eastern belt of which is remarkable as containing in part the gold-bearing veins of

the mother lode. The Palæozoic sediments are called the Calaveras formation. The only evidence of the age of this formation in the limits of the quadrangle consists in rounded crinoid stems found in limestone on Mormon Creek, but the formation is stratigraphically continuous with the Calaveras formation of the Jackson and Yosemite quadrangles, in both of which Carboniferous fossils have been found. The pre-Cretaceous rocks in general are very similiar to those of other portions of the Gold Belt, but two rock types occur here that are rare elsewhere. These two types are certain soda-feldspar dike rocks, called soda-syenite, and a hornblende-pyroxene rock. The soda-feldspar dikes occur chiefly along the mother lode and at many points have been altered by mineral solutions which have deposited calcite, dolomite, pyrite and some gold and silver. East of Jacksonville, at Kanaka Creek, and east of Moccasin Creek, these dike rocks have been extensively exploited for gold. The soda-feldspar dikes (soda-syenite) of the Sonora quadrangle are practically the same as the soda-syenite which forms the lode of the Treadwell mine on Douglas Island in Alaska. The hornblende-pyroxene rock, above referred to, is chiefly remarkable as being apparently unique. The hornblende forms porphyritic crystals in a finer ground mass of augite and hornblende.

The superjacent series is composed of Eocene beds, Miocene beds, andesitic sandstone, auriferous gravels, and various lavas. All of the rocks of the bedrock series were greatly eroded during Cretaceous and early Tertiary time, and upon this old surface of erosion, or approximate peneplain, the river gravels and lavas of the superjacent series were deposited. During Cretaceous and a large portion of Tertiary time the San Joaquin Valley was under water. The sediments deposited at that time, which have been preserved in the Sonora quadrangle, consist of sandstone of Eocene age (Tejon formation), shale, sandstone, clay and rhyolitic tuff of supposed upper Miocene age (Ione formation), and coarse andesitic sandstones and conglomerates which are presumably of Pliocene age. The gravels deposited by the rivers of this period are called the Auriferous river gravels. These river deposits have very largely disappeared through erosion, but are still preserved at some points underneath the lavas of late Tertiary. The best preserved river channel is that underlying the Tuolumne Table Mountain west of Sonora. This mountain owes its table character to a dark basaltic rock (*latite*) which flowed down the valley of the Neocene

Tuolumne river. The low ridges that formed the sides of this Neocene river valley have since that time been worn away by the erosive agencies, leaving the river channel with its hard basaltic capping standing above the surrounding country. At many points tunnels have been run in under the lava capping to penetrate the gravels beds, which have proved highly auriferous at some points. Rhyolite lavas which are so abundant in the Sierra Nevada to the north of the Sonora quadrangle have been found here only in small amount intercalated in the beds of the Ione formation. The andesitic tuffs and breccias, which, at one time, must have covered a large portion of the northern half of the quadrangle, have largely disappeared. The Table Mountain basalt is evidently younger than a portion of the andesite, as it overlies andesitic tuffs and gravels.

Economic geology.—The Sonora quadrangle comprises a portion of the southern part of the mother lode gold district. This remarkable linear system of gold quartz veins extends across the quadrangle in a northwest-southeast direction, and lies partly within the eastern belt of the slates of the Mariposa formation and partly to the east of this belt. Many of the mines are now being operated with good results. Profitable gold quartz veins are also found in the bedrock series, both to the east and west of the mother lode district. The mines in the granodiorite east of Sonora have been worked with varying success for many years. The limestone of the Calaveras formation, which extends from Sonora to the southeast, has been largely metamorphosed into marble, much of which is valuable for building purposes. Chrome-iron deposits occur within the serpentine areas. The sandstones of the Ione and Tejon formations, along the borders of the great valley, are valuable for building stone. The forest zone of the northeastern portion of the quadrangle furnishes valuable timber for the mines and for building purposes.

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THE

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THE ULTERIOR BASIS OF TIME DIVISIONS AND THE CLASSIFICATION OF GEOLOGIC HISTORY.

It was intimated in the introduction to the symposium on the classification and nomenclature of geologic time divisions published in the last number of this magazine that the ulterior basis of classification and nomenclature must be dependent on the existence or absence of natural divisions resulting from simultaneous phases of action of world-wide extent. If there have been such universal phases and if they can be detected, they must ultimately be accepted not only as the true basis of division, classification and nomenclature, but their exposition must constitute the major work of research and of instruction. The most vital problem before the general geologist today is the question whether the earth's history is naturally divided into periodic phases of world-wide prevalence, or whether it is but an aggregation of local events dependent upon local conditions uncontrolled by overmastering agencies of universal dominance.

That there were no universal breaks in sedimentation or in the fundamental continuity of life is not only admitted but affirmed without hesitation. The old doctrine of physical cataclysms attended by universal destruction of life has passed beyond serious consideration. And so, in the judgment of the writer, have all doctrines which attribute profound effects on the life of the globe or the progress of sedimentation to the violence of physical disturbances of any kind. That sedimentation has

been in constant progress somewhere since the inauguration of the pre-Cambrian lands and seas, and that life has been likewise continuous and self-derivative, may be accepted as fundamental postulates. If, therefore, we seek for *absolute* divisions we doubtless seek in vain. But this does not dismiss the question whether this continuity of physical and vital action proceeded by heterogeneous impulses or by correlated pulsations. If the latter, then the history of the earth, when deciphered, will assume a rhythmical periodicity susceptible of natural classification and of significant and rational nomenclature; if the former, the contradictory phases of local actions will inhibit all but the most general unity and render classification and nomenclature either arbitrary or provincial.

I venture to urge three general grounds upon which I entertain the former view. These grounds, if valid, hold out the hope that the history of the earth will be found not only susceptible to natural division, but capable of its truest exposition only through the recognition of its inherent periods.

I. The first of these grounds is the presumption that great earth movements affect all quarters of the globe. Minor stresses may find relief in local readjustment, but profound stresses cannot be relieved, it is assumed, without generating appreciable stresses in other portions of the globe and leading to general readjustment. In a globe, all of whose parts owe their positions to the stress and tension of other parts, every rearrangement that rises in magnitude above the limits of local support extends its influence to the whole. Any massive earth movement must change the gravitative stresses of all parts of the globe unless the movement be divided into contrary phases so adjusted as to be compensatory, the possibility of which in the strict sense may be questioned. The recognized causes of profound movements such as secular refrigeration, change of speed of rotation, progressive molecular rearrangement, and like agencies, are comprehensive in their action and accumulate general stresses whose natural issue is coöperation in a common movement of relief.

The validity of this presumption of general coöperative movements will perhaps not be so much questioned as the mode of their execution. There are those who believe that a downward movement in one region is correlated with an upward movement in some other region. The correlated movements have, therefore, opposite phases and if the distribution of these is not controlled by some unifying agency the general terrestrial effects are heterogeneous, or, if not that, at least uncertain. This view is the natural sequence of the doctrine of a thin, floating crust warping to satisfy its own changes of density and tension, and wrinkling to adapt itself to a shrinking nucleus. Accepting the truth that lies under this view, but rising to a broader generalization, there are those who entertain the conception that the depressions of the earth's surface habitually became more depressed with every readjustment to smaller dimensions (local exceptions aside), while the protuberances became more protuberant. In other words, the oceanic basins became progressively deeper and more capacious, while the continents became higher (degradation aside). In this assumption of habitual downward movements of the ocean bottoms and of correlative upward movements of the continents, there lies, if it be true, a basis for the natural division of geologic events, these movements being in themselves and in their immediate consequences the basis of such division. The full establishment or overthrow of this assumption must await the extension of critical research to at least the major part of the earth, and it is not the purpose of this paper to seriously attempt its advocacy by the citation of the evidence already gathered in its support. Incidentally it will be touched upon in the discussion following.

II. The second ground of belief in a fundamental periodicity in terrestrial progress is founded on the conviction that the major movements of the earth's surface have consisted of the sinking of the ocean bottoms and the withdrawal of additional waters into the basins whose capacities were thereby increased. This belief is not quite identical with the assumption last made, for it does not necessarily involve the simultaneous action of

the different ocean beds, although the conclusions about to be urged would be strengthened if such common action could be demonstrated. But quite apart from this, it is believed the following argument rests upon rather firm observational and inductive grounds except in the matter of two fundamental postulates which are almost universally assumed by geologists. These are as follows: (1) It is assumed that the earth was at first a nearly perfect spheroid, the surface being essentially plane. (2) It is assumed that the great movements of the earth's crust have consisted fundamentally of shrinkage. Probably no serious geologist maintains that the earth has enlarged its average diameter during geological history by expansive action, whatever he may hold respecting local expansion.

These two propositions being accepted, it follows that the radial shrinkage of the ocean bottoms has surpassed the radial shrinkage of the continental platforms to the average amount of some 10,000 or 12,000 feet. This excess of radial shrinkage is to be multiplied by four to measure the excess of volumetric shrinkage, since the area of the ocean bottoms is about four times the area of the continental platforms. The master factor, therefore, in the surface movements of the earth has been the sinking of the ocean bottoms and the formation of the great oceanic basins. Most geologists will probably agree that the continental platforms have also sunk, in the sense that they have shortened their radial distances from the center of the earth. Opinion seems to be divided, however, on the question whether there have been actual epeirogenic uplifts or not. Probably most geologists would regard the rising of the Thibetan plateau in late Tertiary times as involving an actual increase of radial distance. Probably very few geologists would question the absolute elevation of the crests of the loftier mountain ranges. However, the question of absolute as distinguished from relative sinking does not seriously affect the question in hand. If the earth has absolutely grown smaller by some notable amount the average ideal ocean has, as a consequence, grown deeper (if its volume has remained constant), for its circumferential expanse

has been reduced. Aside from this, so far as I can see, our argument holds as firmly for relative as for absolute sinking.

From the greater depths to which the ocean bottoms have sunk, the presumption follows that in every great crustal readjustment the major factor consisted of the descent of the ocean bottom or some part of it. Logically, as here stated, this is only a presumption which might be set aside by the assumption of a single or a few great depressions, while the other movements might be upward or indifferent, but this will appear less tenable in the light of further considerations.

Not only has there been increase in depth, but increase in capacity also. From a capacity essentially zero at the outset the basins have developed a capacity sufficient to hold nearly all the water of the globe. In the aggregate, therefore, the capacities of the ocean basins, as well as their depths, have been increased by crustal readjustment, and the presumption is that this has usually been the case in individual readjustments, although this does not rigorously follow. It will be sustained, however, by further considerations. The crustal readjustments here referred to are those resulting from internal causes. External readjustments work to precisely opposite ends, the degradation of the land and the filling of the basins. This opposing action strengthens the presumption that the internal causes have habitually increased the capacity of the basins, for they have grown more and more capacious in spite of this constantly opposing action. This constant filling in affords a presumption of frequently repeated increases of capacity; otherwise the land should have disappeared.

Proceeding upon the presumption that internal readjustments habitually increased the capacity of the ocean basins, it is important to note in detail the consequences that follow. These are involved in the functions of the circumcontinental terrace, and will be more easily followed after an explicit statement of these functions. These are more or less fully apprehended by all acute students of continental evolution, but like the correlative functions of baseleveling previous to the explicit exposition

of Powell, they have not come into that large service as working principles of which they are susceptible.

Every continent which stands in a given position with reference to the sea for any prolonged period develops a submarine terrace about its borders. This is formed from the débris of the land deposited beneath the edge of the sea. In its initial stages it is nothing more than the familiar shore terrace; but as it develops it becomes a broad submerged platform with a steep face dropping away to the abysmal depths of the ocean. The submerged platform has its outer limit at the depth at which detritus can be effectively moved off shore by the agitation of the surface waters. This, though varying with conditions, may be roughly taken to be one hundred fathoms. The breadth attained by the upper surface of the terrace is conditioned upon the length of time the continent remains in a fixed attitude and the activity of land wash. Simultaneously the sea cliffs are moving inland, and the valleys are developing base plains which are the correlatives of the terrace plain which is growing seaward, as illustrated in Fig. 1.

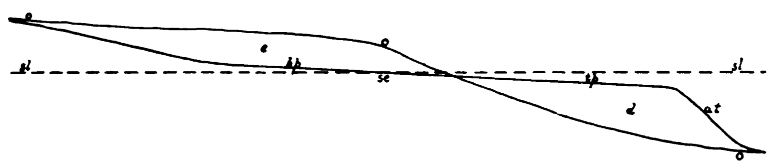


FIG. 1.—*o-o* Original surface. *s l* Sea level. *e* Land carried away by erosion. *d* Detritus built into circumcontinental terrace. *t p* Terrace plain. *a t* Abysmal terrace face. *b p* Base-plain developing landward.

The extreme limit of development is attained when the continent has been baseleveled and no farther detritus is furnished for the extension of the terrace. The baselevel of the continent then becomes essentially continuous with the submerged terrace surface, and the whole constitutes the perfected continental platform, as shown in Fig. 2.

The development of the circumcontinental terrace and of the perfected continental platform is subject to intercurrent disturb-

ances from local and from general sources. There appear to be two systematic sources of slight but very critical modification that require special consideration.

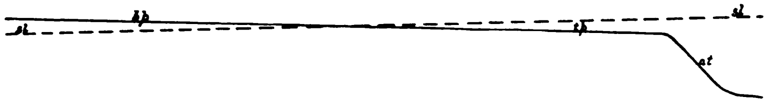


FIG. 2.—*b p* Continental base-plain. *s l* Sea level. *t p* Submerged terrace plain. *a t* Abysmal terrace face.

1. The transfer of débris from the land to the sea displaces an equivalent amount of water, and raises the sea level proportionately, and causes an advance upon the land. The effects are volumetrically small compared with the great body of the ocean, but a slight rise in the surface as the baselevel stages of the continent are attained is peculiarly effective. This coöperates with the cutting back of the sea cliff, and, combined, they become effective in advancing the edge of the sea upon the border of the land.

2. There are both theoretical and observational grounds for the belief that in the process of periodic readjustment of the earth to its internal stresses, portions of the crust are thrust up to heights notably above the plane of isostatic equilibrium, and that these portions gradually settle back toward equilibrium by virtue of the slow fluency or quasi-fluency of the rocks. Recent pendulum studies by Putnam and Gilbert seem to indicate that the portion of our continent most notably lifted in late Tertiary times still stands appreciably above isostatic equilibrium, and there is little doubt that the same is true of other continents, as is, indeed, indicated by partial pendulum data. There is, however, a large mass of concurrent data which shows an aggregate subsidence of the continent since late Tertiary times, data which have been industriously marshaled in the interests of an epeirogenic explanation of the glacial period. This leads to the impression that in late Tertiary times, when the upward move-

ment reached its maximum effects, the land stood very notably above isostatic equilibrium, and that it has been settling back, but has not even now reached isostatic equilibrium. While the generalization cannot be rigorously established, there seem to be sufficient data to warrant entertaining tentatively the doctrine that in periods following crustal upheavals which pass beyond the plane of equilibrium the lifted portions slowly settle back toward equilibrium. If so, this retrocession would coöperate with the filling of the basins in causing an advance of the sea upon the land. At the same time the conditions for the seaward growth of the terrace plain may still continue and the plain be thus simultaneously extended on both borders.

As already noted, the evolution of this peri-coastal plain is subject to interruptions and local modifications to an extent comparable to the interferences in the development of a base-plain, and perhaps to a greater degree, but I think it has like claims to acceptance as an effective general process.

Now the development of such submerged terraces around the several continents for any given period is accurately correlated by the sea level. They are all built immediately beneath its border at a common level. The continental baselevels are correlated by the same controlling horizon. So, necessarily, the final continental platforms are likewise reduced to the same common natural datum plane.

If, therefore, it be admitted that there are periods of general quiescence, it follows that there are periods of simultaneous platform-making just below and just above the sea level on all continents. And this is accompanied by an inevitable tendency of the sea to advance upon the land. Now this submerged sea shelf is the special zone of sedimentation, and hence it is the peculiar locus of registration of geologic events. It is at the same time the peculiar habitat of shallow-water marine life, and this is the life which specially enters into the geologic record. We know almost nothing of the ancient abysmal life and relatively little of the land life. Both the physical and the biological record, which are our chief dependence in reading the

earth's history, are therefore made upon the surface of the peripheral terrace and of its inland extension, and hence this becomes preëminently a critical geologic zone.

To follow out the sequence of a typical cycle, let it be supposed that a circumcontinental submarine platform of ample dimensions has been developed, and that it is peopled by a fauna comparable to its extent and resources. It has been suggested that a typical crust movement has for its major feature the depression of the sea bottom and an increase in the capacity of the basin. Let such a movement succeed. The effect of this, whether it involves one ocean basin or all, must be the withdrawal into itself of water from the submerged platforms of all the continents alike, since the oceans are connected. If the basin movement has sufficient magnitude to draw down the sea surface to the terrace edge, the shallow water zone becomes narrowed to a mere strip on the rapidly shelving abysmal face of the terrace, as illustrated in Fig. 3.

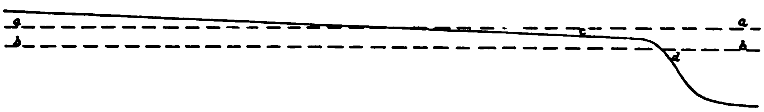


FIG. 3.—*a* Former sea level. *b* Succeeding sea level. *c* Former ample shallow-water tract. *d* Succeeding constricted shallow-water tract.

The ample fauna of the previous broader tract is thus forced into the constricted zone and brought under the direst stress of competition and scant room. The destruction of the larger part is inevitable, and the residue is forced to undergo repressive evolution to meet the severe conditions of the new environment. As this is common to all continents, it constitutes a comprehensive evolution of the severely competitive phase. There would, to be sure, be such exceptions as the local variations from the typical configuration of the continental border afford. These might be very considerable. Portions of the continents may have been previously carried down to moderate depths in the sinking of the ocean basins and may become shallow water ground by

the lowering of the sea level. But even then there would remain a community of dominant action that would give a decisive aspect to the progress of life and to the sedimentation on all continents alike.

If now a long period of quiescence follows, a new universal terrace will begin to form and will extend its marine plain seaward and its baselevel inland until at length an ample zone for the evolution of a new shallow water fauna is provided. If to the cutting of the sea edge and the filling in of the sea basin there be added the settling of the continent, the sea may make a wide incursion upon the low parts of the land, as it did in Cretaceous times, and unusual facilities be thus afforded for that form of life-evolution which follows rich and genial conditions.

Thus on the one hand the sinking sea bottom induces that form of evolution in which stress is the dominant factor, and on the other, quiescence induces that form of evolution in which new ground and rich opportunities constitute the dominant condition. Both of these follow simply and inevitably from the sinking of parts that have been already predominant in sinking, and from prolonged intervening stages of quiescence. Almost the only essential postulate of the one evolution is a periodic increase of sea basin capacity; of the other, periodic quiescence. No profound catastrophe is involved; rather on the contrary it is inhibited by the conditions postulated.

Both the evolution of restrictive environment and the evolution of expansive environment, in the opinion of the writer, are effective in the change of faunas, though their respective results may be as different as their modes. In the rhythmical action postulated there is an alternating application of these opposed evolutionary processes with the natural result of an effect of the maximum order; for the evolutionary effects of restrictive conditions are believed to reach their greatest magnitude when they follow conditions of expansion, and, reciprocally, expansive conditions realize their greatest results when they follow conditions of restriction.

Such a succession of shallow sea incursions and withdrawals

reciprocating with crustal movements and quiescence seem to me to be well indicated as the master features of geologic progress from the beginning of the Palæozoic era to the present time. To these features I look for the primary terms of a natural and permanent system of classification and nomenclature.

III. The third agency which affords some promise of becoming a means for strict correlation of transoceanic events and for the division of these events into their natural epochs is an assumed fluctuation in the constitution of the atmosphere. Too little has yet been learned by direct induction respecting the nature of the successive atmospheres of the geologic periods to render this a firm ground for conclusions, but I venture to invite attention to the doctrine enunciated some time ago[1] that the exposure of the crystalline areas to the action of the air necessarily led to changes in the constitution of the atmosphere, especially in the critical element of carbon dioxide. The principle was urged that the greater the exposure of the decomposable crystalline rocks in area and in elevation, by leading to wider contact and deeper penetration of the atmosphere and atmospheric waters, the more rapid must have been the decomposition of the crystalline rocks and the consequent consumption of carbonic acid in the carbonation of the alkalis and alkaline earths, which is the most important part of the decomposing process. This greater exposure obviously followed the crustal readjustments, for at these times the land was largest and highest. It then not only exposed the greatest surface to atmospheric contact, but the atmospheric waters penetrated deepest because of the hydrostatic pressure arising from great differences of water level. At times of approximate degradation to baselevel and of sea-border encroachment the area of action was reduced and the power of penetration of the atmospheric waters became slight because of the low elevation and consequent slight differential pressure. In a word, the consumption of the carbonic acid proceeded rapidly at times of broad and

[1] A Group of Hypotheses Bearing on Climatic Changes. JOUR. GEOL., Vol. V, No. 7, October-November 1897.

high elevation of the land, and slowly at times of low altitude, grand averages being always understood.

If the atmosphere were once excessively burdened with carbonic acid and its later history has been merely a progressive depletion, these stages of rapid consumption only introduced specially rapid reduction of the superabundant supply, and the effects on tangible geological processes may have been quite beyond detection. But if, on the other hand, the atmosphere was limited in amount at the beginning and has been gradually supplied as well as gradually consumed throughout the ages and has been susceptible to serious change, an unusually rapid consumption of the carbon dioxide at the stages of land elevation would result in appreciable depletion of the atmosphere unless the supply were correspondingly increased. On the other hand, at those stages in which the continents were reduced well toward sea level and the land areas were diminished by the incursion of the ocean, the consumption of the carbonic acid would be checked, and if the supply were not correspondingly reduced, reënrichment in carbonic acid would follow. Under this hypothesis, the history of the atmosphere involved alternate enrichment and depletion.

The carbon dioxide is critical because of that peculiar thermal capacity by virtue of which it retains the heat of the sun to a relatively extraordinary degree, a capacity which is shared by water vapor, but which is possessed in very low degree by oxygen and nitrogen. The amount of aqueous vapor, however, is dependent upon temperature, while the carbon dioxide is stable and active at all terrestrial temperatures. Whenever, therefore, there is a notable percentage of carbon dioxide in the atmosphere, it performs a most important function in conserving the heat of the sun and raising the temperature of the lower atmosphere and of the earth's surface. By this rise it increases the aqueous vapor in the atmosphere, which in turn aids the carbon dioxide in retaining the heat of the sun, the two acting conjointly. On the other hand, when the carbon dioxide is reduced to a small factor, the heat of the sun is less effectually

retained at the surface of the earth, the water vapor enters less into the atmosphere and low temperature and aridity are the consequences.

If these considerations are valid, the history of the earth has been marked by periods of relative cold and aridity resulting from stages of rapid rock disintegration, alternating with periods of warmth and moisture correlated with periods of limited rock disintegration and of carbonic acid accumulation. These stages are genetically connected with periods of continental elevation and rapid subaërial degradation, on the one hand, and with slight degradation and sea incursion, on the other. It will be observed that continental elevation as a purely topographical condition contributes to cold and aridity, while continental degradation correlated with oceanic extension contributes to equalization of temperature and to warmth. We have, therefore, the conjoint action of topographic agencies with atmospheric constitution in producing alternations of cold and aridity with warmth and moisture. The aridity is thought to express itself in salt and gypsum deposits and in the red sediments with which these are habitually associated; the cold, in glaciation; the warmth and moisture, in the polar extension of tropical life.

Now these atmospheric influences are strictly simultaneous for all parts of the globe, latitudinal effects, of course, being neglected, for the diffusion of the atmosphere is such as to render its constitution practically uniform for all parts of the globe. In so far, therefore, as atmospheric conditions of a constitutional nature affect the progress of terrestrial phenomena, they affect them universally, and if these influences are pronounced and can be identified they furnish an additional basis for the strict correlation of transoceanic action and for the division of geological history into its natural epochs.

In summation, therefore, I rest in a somewhat confident hope that under continued study adequate natural bases for the more important divisions of geologic time and for a stable and fitting nomenclature will be found (1) in simultaneous internal readjustments alternating with intervals of relative quiescence, (2)

in the periodic development and emergence of circumcontinental terraces and their critical effects on the evolution of life, and (3) in the successive depletions and enrichments of the atmosphere. For subdivisions of lower order the migration of faunas and the special features of continental development will furnish appropriate bases, and below these again, the local phases of sedimentation and faunal adaptation will afford the provincial terms of a natural classification. If this hope be well grounded, the arbitrary divisions that now vex our system may be largely eliminated.

T. C. CHAMBERLIN.

THE POSTGLACIAL CONNECTICUT AT TURNERS FALLS, MASS.

CONTENTS.

THE familiar slabs of sandstone with fossil footprints from Turners Falls come chiefly from the "Bird Track Quarry," about a mile from that village on the opposite side of the Connecticut River.[1]

The quarry is on the west shore of a little sheet of water known as the Lily Pond, which is steeply walled with rocks on three sides, opening on the north to a tract of marsh and a stagnant arm of the river called the Cove. These details are clearly shown in Fig. 2, giving on a large scale the actual topography of the region about *A* and *B* in Fig. 1. Fig. 2 is *not* taken from the state map.

The Lily Pond is the pool of an abandoned waterfall made by the Connecticut some time since the last glacial epoch, and occupied long enough for it to cut back an eighth of a mile in the Triassic sandstone. When this path was abandoned the river was fifty feet above its present bed. Fig. 3 shows one wall of the little gorge at the point where the quarry is situated, looking across the pond from the opposite side. The quarry is just beneath the pine tree in the center, the rejected slabs forming the talus heap below.

[1] *A*, Fig. 1.

The rocks about the pool are waterworn in precisely the same way as the similar sandstones beneath the present falls at the village. The edges of the shaly laminæ are frayed and rounded

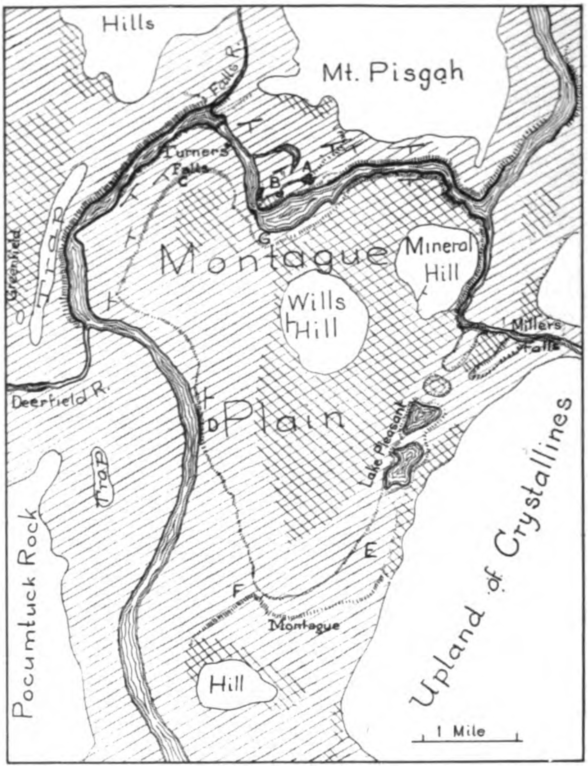


FIG. 1.

as appears in Fig. 4, which is a view of *P* looking from *O* in Fig. 2. Similar effects are observed on all the rocks about.

Besides this fraying of edges, a clear indication of water action, is the complete absence of glaciation about the pool, though elsewhere these sandstones and shales show unmistakable smoothing and grooving on every ledge. Here, despite the rounding in detail, the mass contours of the rocks are sharp and jagged. They have been deglaciated in the rush of waters.

Half a mile further southwest along the same ridge of red shales is Poag's Hole, a similar gorge, somewhat deeper, but of comparable area. Fig. 5 shows the western rock wall. The

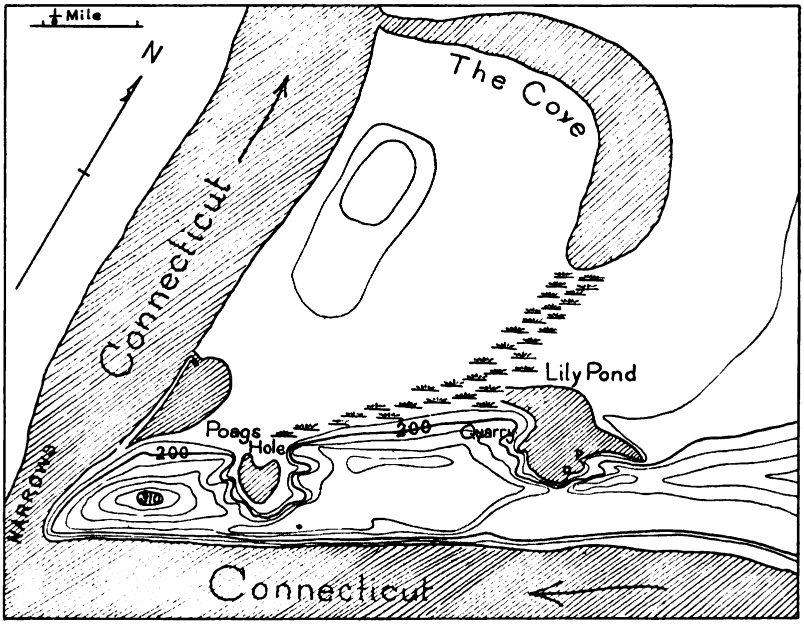


FIG. 2.

crest of the wall at the back is about twenty feet above the crest at the Lily Pond and the sills in front of the pools have nearly the same difference of level. This fall, then, was cut by the river earlier than that at the Lily Pond.

The ridge in which these two gorges are cut has a northern front of exposed shales and sandstones, which strike a little north of east and dip moderately to south. The strata are continuous across the gorges and were once everywhere overlain by clays under sands and gravels, all of glacial origin. The clays are now exposed in the 270-foot flat on the south side of the ridge, between Poag's Hole and Lily Pond. The highest point on the

promontory, west of Poag's Hole, is a cap of gravelly sands that bring it up to the level of Montague Plain, of which it was doubtless once a part, most of the sand and clay having been

FIG. 3.

removed by the river as it cut its way down toward the rock. Fig. 6 is a section through the highest point of the ridge just west of Poag's Hole,

Montague Plain is roughly outlined in Fig 1, the single-lined area suggesting the original extent of the plain formation, and the cross lined part being still at about the original level. The upper portion of the plain is everywhere of sand and gravel somewhat irregularly stratified.

The formation has a considerable extension in Greenfield Meadows and lesser ones to north and south. The gentle undulations of the surface, together with the lack of sharp stratification suggests that the sands were not laid down in standing water, but rather strewn here and there by the detritus-laden

floods from the melting ice on the hills, checked here in their steep descent, and arriving largely through the valleys of the Millers and Falls rivers.

FIG. 4.

Under the sands are clays observed at various levels from 190 to 270 feet above the sea. They rest on the glaciated sandstone, are beautifully stratified, occurring mostly in half-inch layers, greenish and butter-like, with gritty sandy layers from two to four inches thick between. They are exploited for brickmaking at several points in the escarpment around Montague Plain.

In the clay pits beside the track at Greenfield the stratification is clear and horizontal as elsewhere. but the upper surface of the clays, as revealed by the workmen, is uneven and not parallel to the stratification, while the transition from clay to

gravel is abrupt. At Keith's Spring (Fig. 1, *G*), 200 feet above sea, is a little hill of the laminated clays at the foot of the bluff, with its strata running squarely into the sand of the bluff across the intervening air. No other agency than the different rates of atmospheric wear on clay and sand is apparent to account for the notch between the clay hillock and the bluff. A similar hillock of laminated clays occurs half a mile further north. These three occurrences and the varying upper limit of the clays observed point to erosion of the clays before the sands were laid down. Yet in several of the sections the true surface may be masked by sand that has fallen down from above.

The present course of the Connecticut around the plain is of course postglacial and much of it is gorge cut in the rocks. Such rock-cutting is indicated on the map by heavy lines on the river margin. Though superposed on the rock structure underlying the plain this part of the river has now a certain adjustment to the structure as may be seen by the stratigraphic marks on Fig. 1 which indicate well-established facts.

Preglacially the channel was probably straight down from the northeast corner of the map by Millers Falls, and Lake Pleasant and thence westward to the present channel somewhere between *D* and *F*, points where ledges are now exposed.

Between the occupation of the ancient and modern channels there are indications of some persistence of the drainage across the plain by a west channel and an east channel. Indications of water passing through the west channel are:

(1) the gentle depression between *G* and *D* (Fig. 1), and (2) the frayed and waterworn state of a rock ledge at the 220-foot level (*D*), a hundred feet above the present river.

The east channel is better marked, being indicated today by deep sags in the plain at Millers Falls; kettles to the south, two of them occupied by the Lake Pleasant ponds; and the long deep valley to the south by which the lake drainage escapes to the river. The higher ground between the kettles is yet below the surface of the plain. This is shown in Fig. 7, taken

on the higher land between Lake Pleasant and the next kettle to north. The gentle hollow in the foreground represents the ground between the kettles. The tree tops in the middle dis-

FIG. 5.

tance indicate the location of the kettle.[1] Fig. 7 was taken to show that even if the kettles were filled up, there would still remain a shallow valley in the plain. The deeper southern por-

[1] This kettle, like the 100-foot cliff at *D* and some other features, does not appear on the Greenfield topographic sheet. The Lily Pond ridge also is quite misrepresented.

tion of the valley (at *E*) is in the clay, and brickyards are located there.

If the broad valley southwest from Turners Falls between the Greenfield trap ridge and the northwest bluff of Montague Plain was cut out by the modern river, it is remarkable that the cutting should have ceased a few feet above the rocks. But as

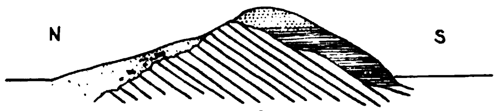


Fig. 6

these are beautifully glaciated and buried under a thin cover of drift, it is hard to believe the water has actually flowed over them. Moreover a curious remnant of sandplain (?) standing on the northwest corner of Montague Plain (at *C*) seems to indicate that ice filled this valley all through the building of the plain. The wearing back of the bluff has cut away most of this sandplain, but a section near Mr. Burnet's discloses the foreset beds and some of the topset. Sands on that side would have come from the hills to the northwest by the valley of the Falls River.

Kettles like those of the east valley we are wont to associate with drift-buried ice blocks. From the alignment with the old upper valley of the Connecticut, as seen in the northeast corner of the map, this chain of depressions might represent the burial in outwash sands of the decayed remnants of a valley ice tongue, the sands being supplied from the earlier revealed hills to north and east. The ice-tongue here however must have rested above the clays, unlike the tongue to the northwest. If this inference is correct, as the clay floor at *E* seems to make it, we must suppose the clays were laid down during a withdrawal of the ice-front from this area while it was either laked or depressed beneath the sea, and that subsequently the ice advanced again to southward, reaching its valley-tongue out over the clays where in the final melting of the ice it rolled

into a number of great fragments and was buried in the sands.

Chief attention is here called to the topographic facts which it is believed are accurately described. The succession of events

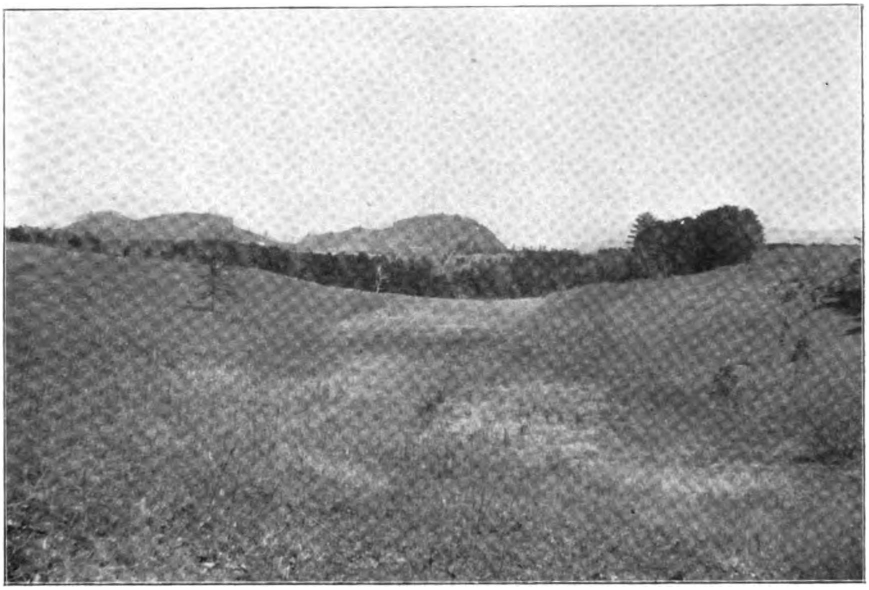


FIG. 7.

which seems most plausible is here offered as an hypothesis for present use. This hypothetical history is as follows:

1. Ice advance.
2. Ice retreat, leaving Turners Falls ice-tongue.
3. Deposition of clays.
4. Ice advance, east valley tongue overriding clays.
5. Ice retreat, leaving east valley ice tongue.
6. Building of Montague Plain and burying east valley ice.
7. Clearer waters pass through west valley.
8. Turners Falls valley ice melts, tempting Connecticut across the ridge where it cut successively Poag's Hole, Lily Pond and the Narrows.

9. East valley ice melts leaving modern topography.

10. The trenching river finds the rocks and cuts its gorge with present falls and rapids.

Ponds, such as those here described should be fairly numerous in glaciated regions. The kettle ponds are of course widely observed.

Pools of abandoned falls of glacial origin are not often cited. A superb example is noted by I. C. Russell[1] at the foot of a 400-foot basaltic cliff near Coulée City, Washington, over which the waters of the Columbia plunged when an ice dam drove them through the fault chasm of the Grand Coulée (p. 91). Another such pool is Thaxter Lake near Taylor's Falls, Minnesota, excavated by the tumbling waters of the deviated St. Croix.[2] Other fine examples are the Green Lakes at Jamesville and other points near Syracuse, reported by Gilbert and lately described by Quereau.[3] Here magnificent glacial outlets of Lake Iroquois, paralleling the Mohawk outlet, but farther south, cut broad trenches across the promontories of the ragged escarpment south of Syracuse and plunged Niagara-like into great basins below. The trenches are now dry high in the hills, but the basins are filled with placid greenish waters.

M. S. W. JEFFERSON.

[1] Bull. 108, U. S. Geol. Surv.

[2] Berkey, Am. Geol. Dec. 1897, p. 352.

[3] Bull. Geol. Soc. Am., Feb. 1898.

THE VARIATIONS OF GLACIERS. III.[1]

THE following is a summary of the Second Annual Report of the International Committee on Glaciers:[2]

RECORD OF GLACIERS FOR 1896.

Eastern Alps.—Nearly all the glaciers are receding, though a few have begun to advance. The Bavarian glaciers show a marked recession.

Swiss Alps.—The advance shown by many glaciers between 1880 and 1893 is fast disappearing. The Rosegg glacier (Engadine) is advancing, as were recently some glaciers on the not distant Ortler.

Italian Alps.—A considerable interest is being awakened in Italy in the variations of glaciers. The Italian Alpine Club, the Alpine Society of Frioul, and the Italian Geographic Society are all encouraging the study of glaciers. Those under observation in the central chain show a marked retreat. Eight glaciers have been examined in the Maritime Alps, and all seem to be diminishing.

Scandinavian Alps.—Much activity is being shown in Sweden in the study of the recently discovered glaciers, but it is still too soon for extensive results. One glacier, the Soltja, has advanced very slightly; the others seem to be stationary. Some interesting temperature observations were made. Minimum

[1] The first two articles of this series appeared in this JOURNAL, Vol. III, pp. 278–288; Vol. V, pp. 378–383.

[2] Archives des sciences phys. et nat., Vol. IV; Geneva, 1897. Some changes have occurred in the membership of the committee. Mr. D. W. Freshfield has replaced Captain Marshall Hall, deceased, as representative for Great Britain and her colonies; Professor G. Marinelli has replaced Professor T. Taramelli, resigned, as representative for Italy; Professor A. G. Nathorst has been appointed to represent Spitzbergen and other Arctic regions not belonging to any civilized nation. We have also to record the sad death of Professor Léon du Pasquier, at the beginning of a career full of promise.

thermometers, placed on the summits of certain mountains, recorded —17° C., against —40° in the neighboring valleys.

Greenland.—Mr. Steenstrup has attempted to determine whether the inland ice has suffered periodic variations, but has been unable to arrive at definite conclusions.

We have a description of the inland ice, written in the year 1200, which would apply to its present condition. A dozen glaciers in the Umanak fiord are the only ones that have been sufficiently studied to yield results of value. Some show no sensible variations; others show variations of rather short periods, dependent probably on the rate of flow. Generally it can be said that there has been no marked change in the length of the glaciers during this century, but the tendency seems to be for an advance rather than for a retreat. A table of twenty-six measures of the velocity of various Greenland glaciers shows motions ranging between one-quarter inch and 124 feet a day.

Professor Mouchketow, representative for Russia, makes the following report:[1]

Caucasus.—Measurements of nine glaciers in different parts of this chain show a retreat varying from 30 to 125 feet yearly for the last eight or ten years; though in the central Caucasus some of the névé fields are growing thicker. About forty glaciers were visited in 1896 in the mountains of Teberda and Maroukha, several of which were unknown before. They are receding, and we may say that the glaciers of the Caucasus are generally in the state of retreat.

Turkestan.—Many glaciers have been discovered in the Ghissar Mountains and the neighboring chains. They are small and do not descend below 11,000 feet. They occur in groups; the majority lie on the northern slopes, and are for the most part entirely covered with snow; this was more general than usual in 1896, on account of the heavy precipitation, which also characterized that year in the Alps. The positions of the moraines show a general retreat of these glaciers.

[1] Professor Mouchketow gives the names and locations of a large number of glaciers.

Siberia.—The principal observations are in the region of Beloukha; the glaciers show a very marked decrease in size.

RÉSUMÉ.

Although it is too early to attempt to form definite conclusions, still the reports seem to indicate pretty generally that the glaciers of the world are getting smaller. The few local cases of advances are of small importance. No region observed shows a general advance of its glaciers such as took place in the Alps in 1816–1820.

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1897.[1]

But little information has been obtained regarding the variations of glaciers in the United States between 1896 and 1897.

Chaney Glacier, a small, steep glacier in the Rocky Mountains of Montana, discovered in 1895, is retreating. (L. W. Chaney.)

Carbon Glacier, on Mount Rainier, has retreated about seventy-five feet between 1896 and 1897. (Plummer.)

Mr. I. C. Russell reports a glacier on Mount Stuart, and Mr. M. W. Gorman reports glaciers on Bonanza and on North Star Mountain, all in the State of Washington.

The glaciers of the Kenai peninsula, Cook's Inlet, Alaska, have been mentioned, but not described, by earlier writers. Mr. F. H. Curtiss has sent me a short description, from which the following is condensed:

The ridge running along the southeastern side of Kachemak Bay is over 3000 feet high; the upper part is covered with snow, from which glaciers descend through deep gorges nearly to the sea level.

The tongues of the glaciers are about five miles long and from three-quarters to one and a quarter miles wide; they all have terminal moraines. A few have been named. The

[1] A synopsis of this report will appear in the Third Annual Report of the International Committee. The report on the glaciers of the United States for 1896 was given in this JOURNAL, Vol. V, pp. 381-383.

Grewingk has apparently retreated about 600 feet in fifteen years. The next glacier to the northeast, though fed by the same fields, seems to have receded very little.[1]

Mt. Iztaccihuatl, in Mexico, has a snow cap from which a small glacier, the Porfirio Diaz or Ameca, protrudes (a second glacier has retreated to the snow-line). Señor Ezequiel Ordoñez, of the Mexican Geological Survey, has put out signals to study its variations. Excellent descriptions and reproductions of photographs of this glacier have been given by Dr. Oliver C. Farrington, of Chicago, with references to the literature.[2]

HARRY FIELDING REID.

GEOLOGICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
June 28, 1898.

[1] A map showing a part of this region, with corrections by MR. CURTISS, has been published by Professor William H. Dall. Coal and Lignite of Alaska, U. S. Geol. Surv. 17th Ann. Rept., 1896, p. 786.

[2] Observations on Popocatepetl and Iztaccihuatl, Field Columbian Museum, Publication 18; Chicago, 1897. Dr. Farrington has overlooked the interesting pamphlet of SEÑOR EZEQUIEL ORDOÑEZ, Notas acerca de los ventiqueros del Iztaccihuatl; Memorias de la Sociedad Cientifica "Antonio Alzata;" Mexico, 1894.

NOTES ON THE KALAMAZOO AND OTHER OLD GLACIAL OUTLETS IN SOUTHERN MICHIGAN.

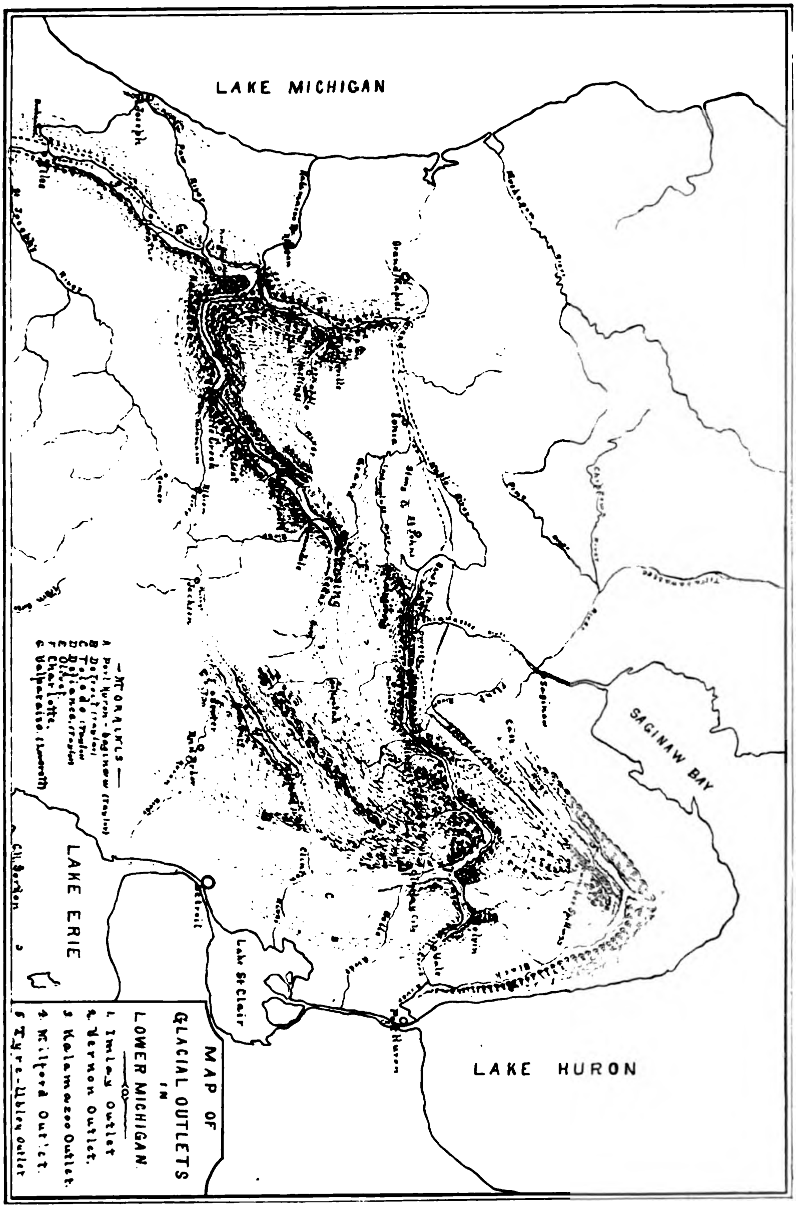
HAVING occasion recently to cross the state from Melvin near Port Huron to Plainwell, the writer took advantage of the opportunity to make the trip by wheel for the purpose of studying some of the problems of glacial drainage suggested by previous studies. It had been observed earlier that between Plainwell and Battle Creek the Kalamazoo River occupies a wide valley evidently of prior origin. Above Battle Creek the valley is much narrower, while a broader channel bears off to the northeast and furnishes an outlet for the Battle Creek. In eastern Michigan the observations of Taylor, Gilbert, and others have disclosed the existence of several old outlets, though the courses of some of them have not been completely traced. One of these, the Imlay, was traced by the above authors northward past Imlay to North Branch, thence southwestward to Columbiaville. Further, in a letter to the writer, Dr. A. C. Lane, Assistant State Geologist, has pointed out the existence of an old channel between Milford and Hamburg Junction, which is now occupied by the Huron River. Did the Imlay outlet discharge by way of the Kalamazoo or was the latter the outlet for the waters of the Milford channel? While the time at the writer's disposal did not permit a full investigation, the facts obtained are deemed of sufficient interest to warrant their publication as a contribution toward the elucidation of the glacial history of the state.

The Imlay outlet.—This outlet, described and mapped by Taylor,[1] was crossed by the writer near its summit level about ten miles southwest of Brown City. South of this point the swamp which marks the position of the channel is drained toward the northeast by Mill Creek. As far as Yale this creek

[1] Bull. Geol. Soc. of Amer., Vol. VIII, 1897, pp. 31–58.

flows in an old channel which probably received the glacial waters when the ice front had retreated to the position of the Detroit moraine at Melvin and poured them westward into the Imlay outlet. Near Columbiaville there are indications that the waters escaped southward toward Lapeer, following the line of the headwaters of the Flint River, while another smaller trough appears to lead southwest, crossing the line of the C. & G. T. Railway just west of Elba. The latter is well situated to constitute the continuation of the Imlay channel, but the elevation of the bottom of the valley, which is about 800 feet, or thirty feet above that of the Imlay at Columbiaville according to Taylor, would seem to militate against that conclusion. The relations here are somewhat obscure and more detailed investigations are needed to settle the question.

The Vernon outlet.—Below Columbiaville the Flint River crosses a moraine which is seemingly the Saginaw, equivalent of the Toledo moraine. At Flint also the river with an abrupt turn breaks through a northward lying parallel ridge which we take to be the equivalent of the Detroit moraine. The valley of the stream where it crosses the first mentioned moraine is much wider than where it crosses the second and has evidently been occupied for a longer time. Before passing through the break in the second moraine it receives a branch from the southwest called Swartz Creek. This stream flows in an old channel which was followed by the writer many miles westward along the south border of the moraine which we may here call the Vernon moraine, from the village of that name which is situated upon its slopes. West of Otterburn the Chicago and Grand Trunk Railway follows the valley bottom as far as Duffield, the stations here being nearly on a level with the valley floor. At Duffield the channel bears directly westward past Vernon. It was followed to a point about nine miles west of this place, or twenty-seven miles in all. The channel has a width of three-fourths of a mile and is covered in part by a black, mucky soil. In places where the drainage is not well established it is wet and swampy. At one point dredging revealed the presence of


LAKE MICHIGAN
SAGINAW BAY
LAKE HURON
LAKE ERIE
Lake St Clair
MAP OF GLACIAL OUTLETS IN LOWER MICHIGAN
1. Imlay Outlet
2. Vernon Outlet.
3 Kalamazoo Outlet.
4. Milford Outlet.
5 Tyre-Ubly Outlet

gravel beneath the muck. Outside the muck area which comprises a belt of varying width extending along the middle of the valley the floor is covered with sandy gravel. Bowlders are not abundant though one field was seen to be thickly strewn with them. Toward the east this portion of the channel is drained by Swartz Creek, which enters it from the south about a mile west of Swartz Creek station, and toward the west it is drained by a branch of Maple River. The middle portion is intersected by the Shiawassee River and one of its branches. The Shiawassee enters the valley about three miles west of Vernon and follows it to the latter place, where it breaks through the moraine northward. The further course of the channel westward is not known, but it probably either continues past St. Johns down Stony Creek or follows the Maple by way of Duplain to the old Grand River outlet. If the Vernon moraine is the equivalent of the Detroit moraine as we infer, then the Vernon outlet must have been active at the time the Mill Creek channel was open at Melvin, the waters from which found their way westward through the bend of the Imlay outlet, though at a later stage the latter may have been abandoned for an outlet farther north, possibly by way of Otter Lake. Within the limits described the known elevations of the channel floor as shown by the railroad levels at the stations named, which are generally within a few feet of the bottom level, are as follows: Otterburn 771, Swartz Creek 779, Crapo 774, Duffield 780, Vernon 780.

The Kalamazoo outlet.—This is one of the most important of the glacial outlets observed within the state. Previous observations had shown the existence of a channel between Battle Creek and Plainwell, but its extension east and west from these points was unknown. Our recent observations have shown that this channel extends northeastward from Battle Creek as far as Lansing, at which point it turns eastward, but beyond which it has not been traced. From this place to Plainwell it follows the outer border of a moraine (*F*), here named the Charlotte moraine from the city of that name which is situated upon it

Between Plainwell and Otsego it turns abruptly southward along the outer border of the Valparaiso moraine (*G*), past Decatur and Niles to South Bend, and thence evidently, according to Leverett's observations, the waters reached the Illinois River by way of the Kankakee. On the south and east side the waters were confined by the Olivet moraine (*E*). Between Lansing and Plainwell the channel has an average width of about a mile, but is somewhat wider in its lower portion. At the bend near Kalamazoo it has a width of two and a half miles and at Plainwell it is much wider. At Plainwell a branch comes in from the northeast by way of Gun Lake that is in direct connection with the upper part of the valley of the Thornapple River which is here wide and was evidently active as an outlet at a later stage than the Kalamazoo. The connection between the Thornapple and Gun Lake divisions is through a series of small lakes and marshes in Yankee Springs township.

Between Dimondale and Charlotte the Kalamazoo channel is marked by a long narrow marsh some portions of which have been brought under cultivation. Similar marshy tracts occur also between Charlotte and Battle Creek, at Kalamazoo and south of Otsego. At Kalamazoo the mucky soil has been utilized for growing the celery for which that city has become noted. Outside the mucky areas the channel floor is covered with sand and gravel. In some places sand predominates and often occurs in low mounds and ridges. Gravel, however, mixed with more or less sand is the principal constituent of the valley filling. Gravel beds occur along the sides of the valley as remnants of a terrace, the top of which is about fifteen feet above the general plain level. Cultivated fields generally show an abundance of cobble stones strewn over the surface and in some places bowlder patches occur. At Charlotte gravels constitute the low divide between the headwaters of Battle Creek and Thornapple River occupied by the Grand Rapids branch of the Michigan Central Railway. At Plainwell a bluff of gravel twenty feet high extends along the north bank of the river which here flows over a stony bottom.

At Dimondale the Grand River enters the valley from the southeast and follows it to Lansing, a distance of nine miles, where, after receiving Cedar River, it passes through the Charlotte moraine northwestward. The marshy tract between Dimondale and Charlotte is drained westward through the Thornapple, while below Charlotte the drainage is effected by Battle Creek. At Otsego the Kalamazoo leaves the old channel and passes out westward through a narrow gorge in the Valparaiso moraine.

The elevations of railroad stations which appear to be situated about on the level of the valley floor are as follows: Lansing (C. & G. T. R. R.) 836, Battle Creek (C. & G. T. R. R.) 823, (M. C. R. R.) 818, Bedford (M. C. R. R.) 807, Augusta (M. C. R. R.) 789, Galesburg (M. C. R. R.) 788, Comstock (M. C. R. R.) 778, Kalamazoo (M. C. R. R.) 770, (G. R. & I. R. R.) 778, Cooper (G. R. & I. R. R.) 774, Travis (G. R. & I. R. R.) 746, Plainwell (G. R. & I. R. R.) 741, Alamo (M. C. R. R.) 764, Williams (M. C. R. R.) 759. If the Kalamazoo channel received the waters of the Imlay outlet during the earlier stage of the activity of the latter, as we are inclined to believe, further investigations will probably show a connection to exist by way of Cohoctah and Lapeer or west of the latter place. However, more detailed work will doubtless bring to light other lines of drainage and until such work is done no reliable prediction can be made. During the time of greatest activity of the Kalamazoo outlet when the edge of the Saginaw lobe occupied the position of the Charlotte moraine and that of the Michigan lobe was at the position of the Valparaiso moraine, the waters from the two opposing ice fronts north of Plainwell evidently came down by way of the Gun Lake branch. Later when the Saginaw lobe had retreated to the north side of the Thornapple River, the principal drainage must have been by way of the Thornapple and Gun Lake channel.

The Milford channel.—The only part of this channel as yet known is the wide valley occupied by the Huron River between Milford and Hamburg Junction. It has been suspected that this channel connected with the Kalamazoo outlet, but from what has

preceded it is evident that the westward extension of the Milford channel must be sought farther south. From the behavior of the rivers and the general character of the drainage it is suspected that the course of this channel lies westward along Portage Creek, a few miles north of Jackson, then southwestward by way of Homer, and thence down the St. Joseph River, joining the Kalamazoo at South Bend.

Reversal of Drainage.—The limited amount of study thus far given to the region has shown the existence of many interesting examples of stream piracy and reversed drainage. The writer has pointed out one of these in the case of Black River near Port Huron.[1] Several others can be readily pointed out on the accompanying map. It is evident that the region of southern Michigan offers excellent opportunity for physiographic study, and the legislature of the state could not perform a better service than to make a liberal appropriation to the geological survey for the purpose of putting this material in shape for the use of the public schools.

C. H. GORDON.

[1] JOUR. GEOL., Vol. V, 1897, p. 315.

NOTES ON SOME IGNEOUS, METAMORPHIC, AND SEDIMENTARY ROCKS OF THE COAST RANGES OF CALIFORNIA.[1]

The metabasalts and diabases of the Coast Ranges.—There are very abundant masses of greenish rocks in the Coast Ranges which are often massive, but sometimes form distinct breccias. The microscopic investigation of these rocks show them to be of igneous origin, and to largely represent old lavas. Many such rocks were supposed by Professor Whitney, the former state geologist of California, to be metamorphic sandstones. Dr. Becker, in his investigation of the quicksilver deposits[2] of the Pacific slope, regarded some of them as metamorphic sandstones, and gave such the name "pseudo-diabase" and "pseudo-diorite." In an investigation of the geology and petrography of Mt. Diablo,[3] I found that some of the so-called metamorphic sandstone of Whitney was true diabase and unquestionably of igneous origin. In this conclusion, Dr. Becker concurred. More recently Dr. Ransome,[4] in a study of the rocks at Pt. Bonita, California, found there similar rocks, which he called basalt and diabase. Still later, Ransome, in an investigation of the geology of Angel Island, found certain greenstones which he considered as allied to fourchite, although admitting that feldspar might have been present in the rock, as indicated by the great abundance of a zoisite-like mineral in some thin sections.

In 1897, in company with Mr. J. S. Diller, I visited Angel Island and collected there specimens of the so-called fourchite, and of other rocks. Some of these specimens show plenty of fresh plagioclase and there is therefore no doubt that some of

[1] The author, doubtless due to absence in the field, has been unable to read the proof of this article.

[2] Mon. XIII, U. S. Geol. Surv. [3] Bull. Geol. Soc. Am., Vol, II, pp. 383–414.

[4] Bull. Dept. Geol., University of California, Vol. I, pp. 71–114.

this greenstone is a feldspathic rock, and not a fourchite. However, if we suppose that the pyroxene in the specimen analyzed by Ransome be an ordinary aluminous augite, and that all the magnesia of the rock is in the augite, a calculation shows that the rock contained about 80 per cent. of augite, so that in this specimen the feldspar must have existed in small amount. The specimens from the Angel Island fourchite area which I examined have the structure and composition of a holocrystalline basalt in which the augite shows an idiomorphic tendency, as it often does in modern doleritic basalts. The Angel Island greenstone may, therefore, be called in part a metabasalt, and this term should likewise be extended to the basaltic rocks at Pt. Bonita, inasmuch as in all cases the basalts have undergone extensive metamorphism. A comparison of the analyses of the spheroidal basalt at Pt. Bonita, with that of the fourchite at Angel Island, and of other greenstones from other portions of the Coast Ranges,[1] brings out very clearly the similarity in composition of these greenstones at widely separated localities.

ANALYSES OF METABASALTS AND DIABASES FROM THE COAST RANGES.

	I Fourchite from Fourche Mt.	II Fourchite from Angel Island	III Diabase, Pt. Bonita	IV Diabase, Pt. Bonita	V Spheroidal basalt, Pt. Bonita
Silica	42.03	46.98	45.59	46.28	49.45
Alumina	13.60	17.07	20.99	12.96	17.58
Ferric oxide	7.55	1.85	2.49	4.67	3.41
Ferrous oxide	6.65	7.02	4.36	6.06	3.41
Lime	14.15	12.15	7.57	10.12	7.20
Magnesia	6.41	8.29	8.95	8.71	4.05
Potassa	.97	.53	4.89	3.75	1.57
Soda	1.83	2.54			5.83
Analyst	Brackett and Noyes	Ransome	Ransome	Ransome	Ransome

1. Fourchite from Fourche Mountain, Arkansas. (Ann. Rept. Geol. Surv., Arkansas, 1898, Vol. II, on "The Igneous Rocks of Arkansas," by J. Francis Williams, p. 108.) This

[1] See table of analyses.

rock is composed of 75 per cent. of augite and secondary material, probably leucoxene, with a highly altered ground mass.

2. Fourchite from Angel Island. (Bulletin Dept. of Geol. University of California, Vol. I, p. 231.) Ransome.

3 and 4. Diabase from Pt. Bonita. (4th Bulletin Dept. of Geol. University of California, Vol. I, p. 106.) Ransome.

5. Spheroidal basalt from Pt. Bonita. (4th Bulletin Dept. of Geol. University of California, Vol. I, p. 106.) Ransome.

	VI Epidiorite-Potrero	VII Pseudo-diabase Mt. St. Helena	VIII Pseudo, diabase, Sulphur Bank	IX Diabase, Mt. Diablo	X Diabase, Mt. Diablo
Silica	47.41	49.08	51.28	51.58	52.06
Alumina	16.03	14.68	15.05	14.99	14.34
Ferric oxide	2.66	1.95	2.41	2.04	2.11
Ferrous oxide	7.05	9.63	8.01	8.36	7.74
Lime	12.33	10.09	7.08	8.59	8.05
Magnesia	5.81	6.69	6.07	6.51	9.26
Potassa	4.47	0.20	0.12	0.31	0.73
Soda		4.60	4.43	3.08	1.74
Analyst	Palache	Melville	Melville	Melville	Melville

6. Epidiorite Potrero. (Bulletin of Geol. University of California, Vol. I, p. 177.) Palache.

7. Pseudo-diabase from near Mt. St. Helena. (Monograph XIII, U. S. G. S., Becker, Quicksilver Deposits, p. 98.)

8. Pseudo-diabase, Sulphur Bank. (Mon. XIII, p. 99.) Becker.

9 and 10. Diabase from Mt. Diablo. (Bulletin Geol. Soc. Am., Vol. II, p. 412.) Turner.

Serpentine.—There are very abundant areas of serpentine in the Coast Ranges, single masses often covering many square miles. The occurrence of serpentine was noted by the geologists who accompanied the Pacific Railroad exploration parties, and the first analysis of a California serpentine which I have found recorded, is that given by Professor Newberry, and is of a specimen collected at the Presidio at San Francisco. Later,

Professor Whitney, in the study of the Coast Ranges, came to the conclusion that the serpentine originated from the alteration of sediments. Dr. M. E. Wadsworth,[1] who studied the Whitney collection of rocks, however, subsequently described some of the serpentines and pyroxenites and peridotites from serpentine areas in California, as probably being igneous rocks. Professor Whitney, under whose supervision Dr. Wadsworth worked, does not appear to have objected to this.

When Dr. Becker undertook the investigation of the geology of the quicksilver districts, the difficulty of accounting for the great change in chemical composition of any sediment to a rock with the composition of serpentine was very apparent. However, he found evidence of such alteration in the sandstones of what is now known as the Franciscan or Golden Gate series. Some of these sandstones contain igneous material, derived undoubtedly from preëxisting igneous rocks or from volcanoes of the Golden Gate period, and some of this igneous material undoubtedly has formed some serpentine. Indeed, needles of serpentinoid material were noted eating their way into grains of quartz, and such evidence led Dr. Becker to conclude that considerable masses of serpentine were thus formed. He suggested that sufficient magnesia for such a metasomatic change might be derived from the micas of the granites which underlie the Coast Ranges. Dr. Becker[2] later (1893), however, regarded some of the serpentine masses described in the quicksilver monograph as being altered peridotites.

In my field work at Mt. Diablo I came to the conclusion that the serpentine there is of igneous origin, as I found traces of the original pyroxene and olivine of the peridotite from which the serpentine was derived at several points. Dr. Charles Palache, in his bulletin on the rocks of the Potrero, San Francisco, likewise concluded that the Potrero serpentine is of igneous origin, and Dr. Ransome treated the serpentine of Angel Island

[1] Lithological Studies. Memoirs Mus. Comp. Zoöl., Vol. XI, Pt. I, pp. 129, 132, 142 and 158. (See also general discussion of the origin of peridotite, pp. 189–192.)

[2] Mineral Resources of the U. S. for 1892, Day, p. 144.

ANALYSES OF SERPENTINES FROM THE COAST RANGES.

	No. 223, Mt. Diablo	No. 176, Mt. Diablo	No. 222, Mt. Diablo	Presidio	No. 78 *b*, Sulphur Bank	No. 181, Mt. Diablo	No. 110, New Idria	No. 78 *e*, Sulphur Bank	Angel Island
Si_2O	34.84	36.57	36.96	39.60	39.64	40.50	41.54	41.86	42.06
Cr_2O_3	0.68	0.33	0.78	.20	0.29	0.41	....	0.24	....
Al_2O_3	0.42	0.95	0.39	1.94	1.30	0.78	2.48	0.69	2.72
Fe_2O_3	6.08	7.29	5.00	....	....	4.01	....	....	
FeO	1.85	0.37	2.34	8.45	7.76	2.04	1.37	4.15	2.88
MnO	0.01	0.10	0.09		0.12	0.13	....	0.20	....
NiO	Trace	0.31	Trace	....	0.33	0.11	0.04	Trace	....
CaO	7.02	0.14	3.81	....	....	0.39	....	....	....
MgO	30.74	40.27	33.84	36.90	37.13	37.43	40.42	38.63	39.53
K_2O	0.07	Trace	0.14	....	....	0.16	....	....	....
NaO	0.42	0.31	0.34	....	....	0.28	....	....	....
H_2O above 100° C	15.72	12.43	14.02	12.91	12.91	10.94	14.17	14.16	12.04
Analyst	Melville	Melville	Melville	Easter	Melville	Melville	Melville	Melville	Ransome

Analyses Nos. 223, 222 176, and 181, from Mt. Diablo are taken from Bull. Geol. Society of America, Vol. II, pp. 383–414. The analyses of the Presidio rock is by J. D. Easter, and is from a report by Professor J. S. Newberry, in the Pacific Railroad report, Vol. VI, Part II, p. 11.

Analyses Nos. 78 *b*, 78 *e*, and 110 are taken from Monograph XIII, U. S. Geol. Surv., by G. F. Becker.

The analyses from Angel Island are taken from the Bulletin Department of Geology, University of California, Vol. I. p. 106.

as a metamorphosed igneous rock. The Angel Island rock was, however, considered as possibly being derived chiefly from diallage, but the analysis given shows clearly that no such derivation is possible. The table of analyses given below indicates how uniform in chemical composition the serpentines of the Coast Ranges are, and also that olivine or rhombic pyroxine must have been a prominent constituent of all of the original rocks from which the serpentines analyzed were derived.

The Franciscan or Golden Gate formation.—The metamorphic rocks of the Coast Ranges, and the associated cherts, sandstones, and shales, were formerly considered as of the age of the Knoxville beds; that is, lower Cretaceous. The more highly metamorphosed of these rocks are green amphibolite-schists, blue amphibolite-schists (glaucophane-schists), mica-schists, chlorite-schists, and various other schistose rocks. In my bulletin on Mt. Diablo, it was assumed that the red cherts or jaspers were silicified shales, and that these jaspers, together with the sandstones and schists associated with them, were the result of regional metamorphism of the Knoxville formation. Since that time it has apparently been shown, chiefly by Dr. H. W. Fairbanks, that these jaspers, associated sandstones, and schists are older than the Knoxville beds, and probably of Jurassic age. The best description of this series of rocks is that by Professor A. C. Lawson in his "Sketch of the Geology of the San Francisco Peninsula."[1]

One of the most interesting rocks of the series is the blue amphibole-schist, which is often found in croppings in or near serpentine masses. The blue amphibole is perhaps in part glaucophane, and these rocks have, therefore, generally been called glaucophane-schists. Dr. Ransome, in his study of the geology of Angel Island, found these schists at so many points on the border of serpentine masses that he concluded that they were contact metamorphic rocks. Professor Lawson, in the paper above referred to, considered the schists rich in amphibole to be metamorphosed volcanic material, but ascribed their origin, in

[1] Fifteenth Ann. Rept. U. S. Geol. Surv.

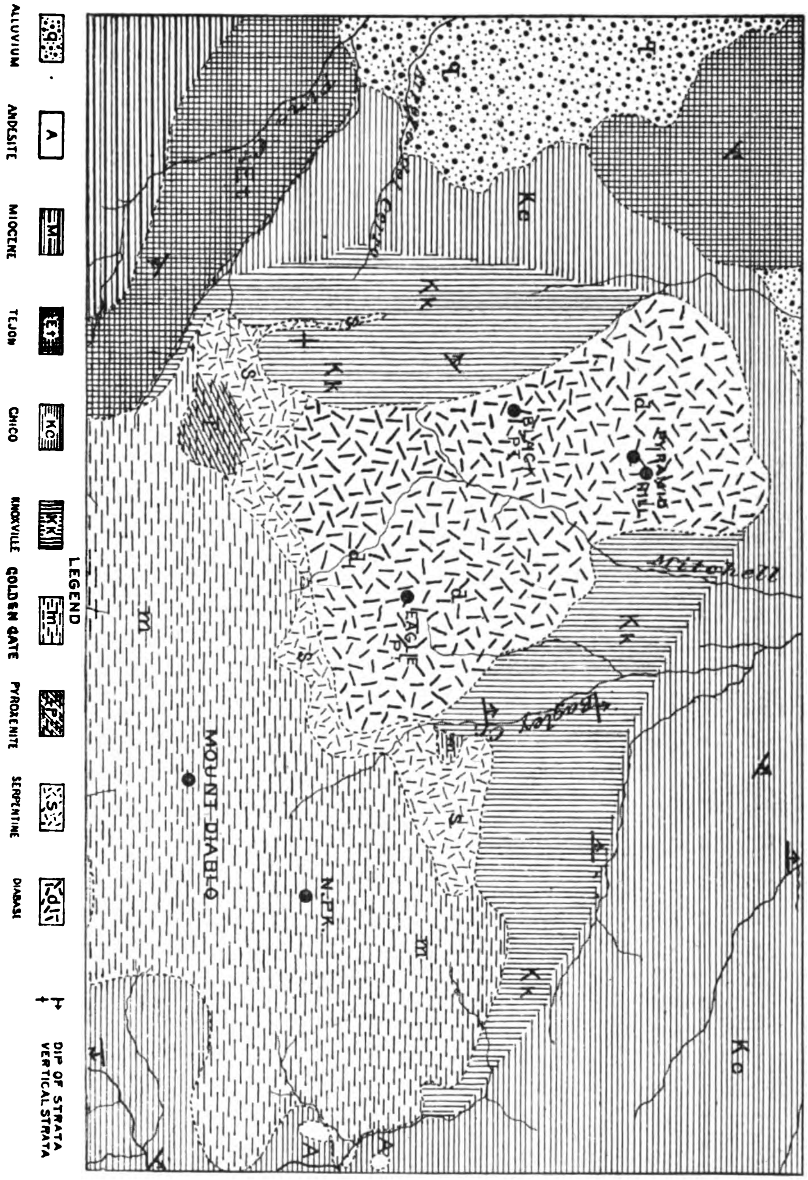
part at least, to contact metamorphism, and not regional metamorphism, believing that Dr. Ransome has established this in his bulletin on Angel Island. Professor Lawson seems to me to state the case very fairly. He writes as follows:

"In some few cases the schist areas have a very definite relation to dikes and laccolitic lenses of serpentine, and some of the most highly altered phases of schist that have been found, both of the micaceous and the blue amphibole varieties, have been taken from the immediate contact with the serpentine. In these cases there seems to be little doubt that we are dealing with a contact zone. In other cases, however, we have the immediate contact of serpentine and sandstone well exposed with no perceptible development of schist at the contact and little alteration of any kind appreciable to the unaided eye beyond a narrow zone of hornfels. It seems clear, therefore, that the metamorphic action of intrusive peridotite upon the rocks which it invades is not uniform, and the conditions which determine in some cases a maximum and in some cases a minimum of metamorphism are not yet known."

The point Lawson makes, that serpentine in many cases has merely hardened the sediments into which it is intruded and has not metamorphosed them, is perhaps of vital importance in discussing the origin of these schists. In the case of granitic intrusions into sediments, as everybody knows, there is always a zone of metamorphism all around the mass, and the conclusion that the granitic rock has caused this metamorphism appears to be absolutely demonstrated. When, therefore, we have an igneous intrusion which is bordered by schists on one side and by little altered sediments on the other, and if we know the latter to be older than the igneous mass and intruded by it, it is difficult to imagine conditions which cause such variable effects if we ascribe the formation of the schists to contact metamorphism. Such a case may be finely seen at Mt. Diablo. Here a dike of serpentine about 6.6^{km} long and 800^{m} wide extends in an east and west direction from the north flank of the mountain to near the east fork of Pine Creek. (See the geological sketch map of

Mt. Diablo.) On the south, this serpentine dike is flanked chiefly by the rocks of the Golden Gate series. On the north, at its east end, it is in contact with the shales of the Knoxville formation, and also, at its west end, in the upper drainage of the Arroyo del Cerro. At both points, it has effected no appreciable alteration of the Knoxville formation. In the Arroyo del Cerro drainage, the intrusive nature of this serpentine is beyond all question. The shales here stand nearly vertically with a strike in the neighborhood of the serpentine, approximately north and south, and a narrow apophysis of the main dike extends north into these shales for nearly one mile. This dike is cut by the Arroyo del Cerro and smaller streams, and in the ravines of these streams the dike nature of this serpentine apophysis can be clearly seen. The accompanying geological map shows the serpentine dike here described with the narrow apophysis extending north into the Knoxville shales. The area of the Golden Gate formation (*m*) in reality includes considerable masses of igneous rocks, chiefly metabasalt and serpentine. Thus the north peak is composed of a metabasalt which is said by Ransome to exhibit a spheroidal structure.

The Golden Gate series at Mt. Diablo, as elsewhere, however contains large amounts of igneous material which would more readily undergo recrystallization than the argillaceous and siliceous material of the Knoxville formation. It seems, therefore, possible that any contact metamorphism which the original peridotite of the serpentine dike might exert, would show more pronounced effects on the sediments of the Franciscan or Golden Gate series than on the material of the Knoxville formation. In addition to the large dike there are smaller masses of serpentine at various points along the flanks of the mountain. Glaucophane-schist is found near some of these serpentine croppings; in some cases exactly alongside of them; in other cases, it is not at the contact, but forms isolated croppings along with green amphibole-schists and micaceous schists. It would be unwise to insist that these schists have not resulted from the metamorphism of igneous material, by intrusive igneous masses, but it



GEOLOGIC MAP OF THE VICINITY OF MOUNT DIABLO, CALIFORNIA.

appears to me, in view of the foregoing facts, that it is yet to be demonstrated that these schists are the result of contact metamorphism of the peridotite intrusions. In any case, it seems clear that the glaucophane-schists and the green amphibole, garnet, and micaceous schists associated with them, are all caused by the same kind of metamorphism.

An investigation of the geology of the Bidwell Bar quadrangle, in the northern Sierra Nevada, has brought to light the existence of large areas of magnesian schists, associated with serpentine. These magnesian schists are composed of talc, chlorite, and various amphiboles, among which are prominent certain colorless amphiboles approximating to edenite and gedrite in composition. The microscopic investigation of these rocks clearly shows that these magnesian schists are alteration products of rocks of the same general nature as those which form the serpentine; that is to say, of rocks of the pyroxenite-peridotite family. The serpentine itself, no doubt, was largely formed from those masses rich in olive or rhombic pyroxene, and the various schists from aluminous pyroxenic facies of the magma. Many of these masses form croppings in and along serpentine masses, but they also form isolated areas of considerable extent. To conclude that any of these schists were formed by contact metamorphism would certainly in this case be erroneous, for not only can their composition be accounted for by supposing them to be alteration products of various pyroxenes, but their formation from these pyroxenes can in many cases be seen in the thin sections of the rocks.

If, as thought by Fairbanks, the Franciscan or Golden Gate series is older than the Knoxville, its generally hardened and altered character may have been the result of a pre-Knoxville metamorphism; for the beds, which have been determined as Knoxville, are nowhere much altered. It may then be advanced as a working hypothesis that the entire schist series of the Golden Gate formation was formed before the deposition of the Knoxville, and before the intrusion of at least some of the serpentine. If this be true, pebbles of some of these schists should

be found in the conglomerates of the Knoxville formation. Such conglomerates were observed at Knoxville, in Napa county. When making a geological map of the Knoxville quicksilver district for Dr. Becker, I collected some pebbles from these conglomerates, and later published[1] a few notes concerning them. As the characteristic fossil of the Knoxville formation (Aucella) occurs in this conglomerate, there can be no doubt concerning its age. The pebbles are of various porphyries, including soda-syenite porphyry and augitic porphyries and fine cherty pebbles, indistinguishable from the rocks called phthanites by Becker, radiolarian cherts by Lawson, and jaspers by Whitney and Fairbanks. A thorough investigation of these conglomerates will, perhaps, bring to light pebbles of some of these schists, the origin of which is ascribed to contact metamorphism and thus make certain their pre-Knoxville age. This being established, it would at least be certain that these rocks, if formed by contact metamorphism, were not formed by the serpentines which are found intruded into the Knoxville formation.

To the southeast of Coulterville,[2] in Mariposa county, and at other points, there are dikes of soda-feldspar, which are frequently intruded along the contact of serpentine masses with other rocks. These soda-syenite dikes, where altered, often contain blue amphibole in varying amount. Some of this may be primary, but part of it is secondary, The formation of glau cophane-schists (soda-amphibole) from crushed rocks containing much albite (soda-feldspar) seems quite possible. This is heightened by the finding by Ransome of white bunches composed of albite, in association with the glaucophane-schists on Angel Island. The suggestion of such an origin for the glaucophane-schists of the Coast Ranges should not, however, be taken too seriously.

Fossils being rare in the Golden Gate formation, all localities where remains have been found are worthy of note. About one mile (1.6 klms.) northeast of the summit of the north peak

[1] Am. Geol., Vol. XI, May 1893, p. 316.

[2] 17th Ann. Rept., U. S. G. S., Pt. I, p. 729.

of Mt. Diablo, in a ravine above the house of young Ben Dixen, fossils were found by Mr. F. M. Anderson, a student at the University of California, to whom I am indebted for the information. In company with Dr. Merriam, I visited this locality in 1897. We found more fossils there in thin, shaly layers in the hardened sandstone of the Golden Gate formation in a ravine above the house. This ravine heads just northeast of the north peak, and has a northeasterly course to about the fossil locality, where it turns sharply to the east. We collected some lamellibranchs here, which were not, however, specifically determinable. The sandstone is much intersected with fractures and can be readily broken out. This locality will probably afford more material, if carefully worked. Dr. T. W. Stanton, who saw Mr. Anderson's fossils, thought that the forms belonged to the *Cyprinidæ* or *Veneridæ*, but was unable to express a positive opinion concerning them.

The San Pablo formation. — At Kirker Pass,[1] north of the Mt. Diablo, south of the mountain at the Railroad Ranch reservoir, and at Corral Hollow, there are beds containing large amounts of volcanic detritus, as well as fossil shells and plant remains. The beds at Kirker Pass and Corral Hollow were first made known through the investigations of the State Geological Survey, under Professor Whitney. At a later date I visited the three localities above named and collected fossil plant remains at all of them, and fossil shells at two of them. The plant remains were studied chiefly by Professor Lesquereux, who assigned some of them to the Pliocene and others to the Miocene. The fossil shells were examined by Dr. Dall, who considered them to indicate a Pliocene age. Dr. Gabb had previously collected quite a series of fossil shells at Kirker Pass, and on that basis called the beds Pliocene.

In October 1897, in company with Dr. J. C. Merriam, I again visited Kirker Pass, and we collected there fossil shells and

[1] This pass is named after a Mr. Kirkwood, but the name Kirker having been used in geological literature for a long period, it is perhaps inadvisable to change the name to Kirkwood Pass.

plant remains, and I am indebted to Dr. Merriam for the following list of marine fossils from the Kirker Pass locality:

Fossils from San Pablo formation near Kirker Pass, north of Mt. Diablo, Contra Costa county, California. Collected by Gabb, Turner, and Merriam.

1. *Astrodapsis whitneyi* Rémond.
2. *Astrodapsis tumidus* (?) Rémond.
3. *Pseudocardium gabbi* Rémond.
4. *Ostrea Bourgeosii* Rémond.
5. *Ostrea titan* Rémond.
6. *Pecten pabloensis* Con.
7. *Pecten (Liropecten) crassicardo* Con.
8. *Cyrena californica* Gabb.
9. *Tapes staminea* Con.
10. *Tapes staleyi* (?) Gabb.
11. *Dosinia ponderosa* Gray.
12. *Gari alata* Gabb.
13. *Standella falcata* Gld.
14. *Saxidomus squalibus* Dash.
15. *Cardium blandium.*
16. *Macoma nasuta* (?) Con.
17. *Solen* sp.
18. *Mytilus* sp.
19. *Modiola* sp.
20. *Zirphæa* sp.
21. *Littorina remondi* Gabb.
22. *Littorina planaxis* Phil.
23. *Trophon ponderosum* Gabb.
24. *Ranella californica* Hds.
25. *Purpura saxicola* Val.
26. *Lunatia lewisii* Gld.
27. *Crypta grandis* Midd.
28. *Crepidula adunca* Sby.
29. *Calliostoma* n. sp. (?) Merriam.
30. *Ocinebra lurida* (?) Midd.
31. *Trochita filosa* Gabb.
32. *Trochita* n. sp. Merriam.
33. *Olivella boetica* Cpr.
34. *Bittium asperum* Cpr.
35. *Fusus* Gld.
36. *Purpura canaliculata* Duc.

This list contains 5 forms belonging to the Miocene, 2 (5?) forms belonging to the Merced formation, and 11 forms found elsewhere in the San Pablo formation.

There are 17 extinct and 14 living species, and the formation may, therefore, be regarded as of lower Pliocene age, on the basis of the ratio of the living and fossil forms.

In a recent paper,[1] on the Neocene sea-urchins, Dr. Merriam refers to the beds at Kirker Pass and similar beds at other points containing tuffs and volcanic ashes, as the "San Pablo formation." He considers the sea-urchins, belonging to the genus Astrodapsis, as particularly characteristic of this formation, inasmuch as he has not found them outside of it, and his information concerning the formations covers other localities besides those mentioned in this paper. This series of strata will then hereafter be spoken of as the San Pablo formation. In the bulletin, above referred to, Dr. Merriam concludes that this formation is of Middle Neocene age, including the top of the Miocene, and the base of the Pliocene. In my bulletin on Mt. Diablo, I called attention to the similarity of the plant forms in the San Pablo formation of the region about Mt. Diablo with the plant remains of the Auriferous gravels formation of the Sierra Nevada. The collections of the plant forms from the Coast Ranges are not sufficient to narrowly correlate the plant remains from the two regions, but it is clear that the marine fossil shells of the San Pablo formation furnish a more certain criterion for determining the exact horizon of the formation, than do the plant remains.

When the plant forms of the San Pablo formation have been collected in greater number and thoroughly studied a comparison can then be made between the floras of the Auriferous gravel series, and of the San Pablo formation, and the age of the auriferous gravels decided on that basis. As pointed out in an article on the Auriferous gravels,[2] it is certain that the fossil leaves collected from different localities in the Sierra

[1] Bull. Dept. Geol. Univ. of California, Vol. II, p. 116.

[2] American Geologist, Vol. XV, June 1895.

Nevada from the Auriferous gravels formation represent different horizons; nevertheless, no distinction has been made thus far by the palæobotanists, who have examined the different collections. It is, therefore, probable that, when studied, certain of these localities will be found to furnish a flora similar to that of the San Pablo formation, and other localities will furnish floras of a somewhat older date. In general, in recent years, the fossil plant remains of the auriferous gravels have been called Upper Miocene. It is more than likely that some of these localities are of Pliocene age. There is published herewith, a section of the San Pablo formation at Kirker Pass, north of

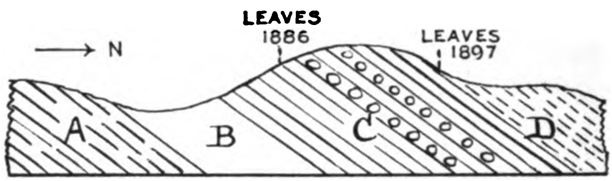


FIG. 1.— Section of the San Pablo formation on the Hyde Ranch, north of Mt. Diablo. The horizontal extent of the section is about 600 meters. The section, however, does not necessarily include the top or the base of the formation at this point. A = White shales and rhyolitic tuff; B = Fossiliferous sandstone; C = Andesitic tuff, sandstone, and conglomerate; D = Shale and pumice.

Mount Diablo. The horizontal extent of the beds shown in the section is 600 meters. The beds dip uniformly to the north at an angle of about 35° and thus have a thickness normal to the bedding of about 350 meters, or about 1150 feet. The section given above (Fig. 1) is drawn without reference to scale, merely to show the relations of the different members of the formation. The basal portion (A) of the section is composed of fine-grained white shales, and volcanic detritus, which Dr. Merriam has noted at other localities in the formation, and he regards this as its base. An optical examination of volcanic glass which forms certain layers in these white shales, shows the glass to be of rhyolitic composition. There is given below an analysis, No. 399, of a specimen of this glass. This analysis shows that the rhyolite has undergone leaching, having lost both alkali and silica, as is

very frequently the case with layers of volcanic glass and pumice. Overlying this basal volcanic series are some sandstone beds (*B*), which have offered the majority of the marine fossil shells from this locality. Lying upon fossiliferous sandstones are a set of blue beds (*C*), composed of volcanic conglomerate, tuff and sandstone. The tuffs and volcanic conglomerates are derived from andesite, containing hornblende and pyroxene. These andesitic tuff beds contain abundant silicified wood, and the first list of fossil leaves given below collected in 1886, came from a fine layer in this tuff series.

These leaves were studied by Lesquereux, who published a list of the species identified in the proceedings of the U. S. National Museum (Vol. XI, 1889, p. 35), as follows.

Fossil leaves from the San Pablo formation on the Hyde Ranch, collected in 1886.

Diospyros virginiana 1, var. turneri, Lx.
Magnolia californica Lx.
Laurus, cf. *canariensis* Heer.
Virburnum, cf. *rugosus* Pers.
Vitis, sp. (?).

These are considered to be probably Pliocene, although on page 11 of the same publication, the same collection is referred to the Upper Miocene. These leaves come from a fine layer in the blue andesitic sandstones which form a higher horizon than the bed which afforded the most of the fossil shells given in the previous list by Dr. Merriam.

The leaves collected in October 1897, came from a bed conformably overlying the blue andesitic sandstones, and underlying the volcanic pumice represented by specimens 345 (Series D). Immediately underlying the leaf layer, is a light colored layer, containing specks of pumice in which are fossil shells. One of these, is an Astrodapsis, as determined by Dr. Merriam, which is considered as characteristic of the San Pablo formation. This second set of leaves came from a higher horizon of the San Pablo formation than those collected in 1886. The leaves collected in 1897 were referred to Professor F. H. Knowlton

of the National Museum, who reports as follows concerning them:

Six species of plants are represented:

Fern, probably *Pteris*, but very fragmentary.
Populus, female Catkin.
Alnus, fruits and leaves.
Castanea, sp. leaf.
Vaccinum, sp. single small leaf.
Arbutus, sp. Numerous well-preserved leaves and fragments.

I have not been able to identify any of the above mentioned material with anything from California. The forms all have a very modern aspect, the more abundant being the Arbutus, which is close to the living form.

As to the age, I do not think there can be any doubt about their being Pliocene. They certainly cannot be older.

The conclusion of Professor Knowlton that the plant remains in 1897 are certainly not older than Pliocene, would not appear to conflict with the conclusion of Merriam as to the Middle Neocene age of the formation as a whole, inasmuch as these leaves came from near the top of the formation, as exposed near Kirker Pass. Overlying the plant remains above noted, are some layers of volcanic pumice (*D*), of which specimens were collected. An examination of this material under the microscope shows that it has been much altered by infiltrating waters, but that the glass has a rhyolitic composition, as indicated by its low index of refraction. A chemical analysis of one specimen, No. 345, shows, as does the analysis of No. 399, that the pumice has undergone leaching, resulting in a loss of silica and alkali. All of the plant remains obtained by myself at Kirker Pass came from the Hyde Ranch, and were collected in a field west of the road from Cornwall to Summersville. The locality of 1897, is on the north slope of a low hill, and about 430 meters south of the house of George South.

The San Pablo formation, at Corral Hollow, has afforded nineteen species of fossil plants. A few of which have been identified in the Auriferous gravels flora. The plant beds at Corral Hollow, from which the specimens came which I collected, underlie andesitic tuffs, and conglomerates, which are

quite like those of the San Pablo formation, in the Mount Diablo quadrangle. It is, therefore, likely that the Corral Hollow plant remains represent a somewhat older horizon than those collected near Kirker Pass.

ANALYSES OF RHYOLITIC TUFF FROM THE SAN PABLO FORMATION, BY WILLIAM VALENTINE.

	No. 339. Near base of San Pablo	No. 345. Near top of San Pablo
SiO_2	63.28	63.28
CaO	1.90	1.18
K_2O	2.44	0.78
Na_2O	1.82	0.56

The Merced formation of Lawson,[1] which has been referred to, is probably younger than the San Pablo and of Upper Pliocene age. The Merced formation is named from Merced Lake, in the vicinity of which the beds are extensively developed. It is probably identical with the Wild Cat series of Humbolt county, described by Lawson,[2] in which case the latter name should be dropped. As pointed out by Lindgren,[3] the correlation by Lawson on the Merced series with the Auriferous gravels formation is probably incorrect. It is far more likely that the Auriferous gravels series is in part contemporaneous with the San Pablo formation, and in part older than that formation.

H. W. TURNER.

[1] Bull. Dept. Geol. University of California, Vol. I, pp. 142–149.

[2] Bull. Dept. Geol. University of California, Vol. I, pp. 255–263.

[3] JOUR. GEOL., Vol. IV, pp. 904, 905.

STUDIES FOR STUDENTS.

THE DEVELOPMENT AND GEOLOGICAL RELATIONS OF THE VERTEBRATES.

II. AMPHIBIA.

THE *Amphibia* may be described as forms that live a portion of their lives, at least, in the water or in a condition fitted for an aquatic existence; the latter statement is necessary from the fact that some forms never live in the water, but develop external gills such as are found in the forms which do pass the larval stage as aquatic forms. All amphibians pass through a metamorphosis in which the external gills of the immature forms are lost and lungs developed. The skull presents some peculiarities; the whole base of the cranial region is covered by a large presphenoid bone that extends far forward as well as backward. In the more highly developed types of the vertebrates this bone occupies a minor position anterior to the basi-occipital. In many of the more primitive forms of the amphibians the bones of the cranial region are largely cartilaginous; the extremities of the long bones of the limbs are without the epiphyses, or separate ossifications, that are found in the mammals, and the ribs are attached each to a vertebra instead of intervertebrally as in the higher forms.

That the *Amphibia* were derived from the *Pisces* is without question, but from what branch of the piscine stem they were developed has been the subject of much discussion. For a long time they were supposed to be derived from the *Dipnoans*, and from forms that were very close to the existing genera of the order. This idea is still supported by Haeckel (*Systematische Phylogenie der Wirbelthiere*; Berlin, 1895). In discussing the question, Baur said (The Stegocephali: a phylogenetic study;

Anatomischer Anzeiger, Band XI, Nr. 22, 1896, p. 659) "That the *Stegocephali* (the most primitive of the amphibia) did take their origin from a group of fishes is evident. The question to examine is: Which was this group?"

"In the Devonian preceding the Carboniferous, where the *Stegocephali* first appear, we have the following groups of fishes: The *Elasmobranchii*—including the *Holocephali*—*Ostracodermi*, *Dipnoi*, *Crossopterygii* and *Chondrostei* (this last group corresponds to the *Actinopterygii* of the present studies). The *Elasmobranchii* have no dermal ossifications in the skull, they are therefore out of the question; the *Ostracodermi* have, of course, nothing to do with the *Stegocephali;* we also can exclude the *Chondrostei* represented by *Cheirolepsis*. Only the *Dipnoi* and the *Crossopterygii* remain.

The dentition of the *Dipnoi* is already so much specialized in the Devonian, that it is impossible to derive the *Stegocephali* from them. We have now to consider the *Crossopterygians*. The *Crossopterygii* were established by Huxley, in 1861, to contain the living *Polypteridæ* of Africa and the extinct *Holoptychidæ*, *Rhizodontidæ*, and *Osteolepidæ*, having lobate paired fins with an endoskeletal axis, more or less fringed with dermal rays. The *Crossopterygii* are the most typical fishes of the Devonian. There is no difficulty in homologizing the premaxillaries, nasals, frontals, parietals, prefrontals, and postfrontals in the *Crossopterygii* and the *Stegocephali*." Here the author proceeds to prove from the course of the grooves upon the skulls of certain of the more primitive of the fishes and the amphibians, which mark the course of the sensory tracts of nerves in the living form, the homology of the skull bones of the two groups and the close connection that exists between them.

In a further discussion of the homology of the ribs he concludes that the "ribs of the oldest *Batrachia*, the *Stegocephali*, are not homologous with the ribs of the *Dipnoi*; therefore the *Dipnoi* cannot be the ancestors of the *Stegocephali*," and "the *Batrachia* must have developed from the *Crossopterygii*."

The *Amphibia* may be classified as follows:

Class, AMPHIBIA.
  Order, *Labyrinthodontia.*
    Suborder, *Branchiosauria.*
      Microsauria.
      Aistopoda.
      Labyrinthodonta vera.
        a, *Embolerimi.*
        b, *Rachitomi.*
        c, *Labyrinthodonti.*
  Order, *Coecilia.*
    Caudata (*Urodela*).
    Suborder, *Salamandrina.*
      Icthyoidea.
  Order, *Ecaudata* (*Anura*).
    Suborder, *Arcifera.*
      Firmisterna.
      Aglossa.

It is with the first of these orders that the student of palæontology is the most concerned, as they were the predominant forms of life during the Carboniferous time and even during the first part of the Mesozoic. The other orders did not assume any importance before the beginning of the Tertiary, and only one of them, the *Caudata*, appeared as early as the Cretaceous.

The earliest trace of amphibians is found in the Devonian rocks of Warren county, in Pennsylvania, and consists of tracks of some large labyrinthodont that Marsh has called *Thinopus antiquus* (*Am. Jour. Sci.*, 1896). No other trace of the *Amphibia* has been found in rocks earlier than the Carboniferous, but with the appearance of that time a large number of forms were developed that in the variety of their forms and the degree of their specializations rivaled the development of the reptiles of later times. To this large group of semi-aquatic forms Huxley gave the name *Labyrinthodonta* in 1863; five years later Cope gave the name *Stegocephali* to the same group. The latter name is used the most commonly in this country.

In external appearance the *Labyrinthodontia* were very similar to the existing tailed amphibians, the body was long in some cases and in others more stout and heavier; the skin was naked,

but in most cases, on the ventral surface, at least, protected by the development of small dermal ossicles of bone; the legs were in most of the forms rather short and weak, and in some cases were entirely atrophied as in the recent snakes; the bones of the more primitive forms were quite largely cartilaginous, the carpus and the tarsus of some forms being almost entirely so, and even the long bones of the limbs and the bones of the skull were incompletely ossified; the skull was completely roofed over by dermal bones developed in the skin of the head, leaving only five openings in the skull, the two nostrils, the orbits, and the pineal foramen, the last a single opening on the upper surface of the skull. The teeth of most of the forms, and of the more highly developed forms of the Trias especially, are notable for the peculiar infolding of the enamel, giving the internal structure of the tooth a most complicated appearance.

The structure of the spinal column in the various forms is of especial interest, as it parallels in the first stages the history of the spinal column of the fishes and takes the process a few steps farther. In all of the *Labyrinthodontia* the notochord is to a greater or less extent persistent. In the simplest of the *Amphibia* the chord is very large and the vertebræ are represented by small plates arranged in pairs on the upper and lower surface of the chord; to these plates are attached the spinuous processes and the hæmal arches that protect respectively the spinal chord and the nutrient arteries (in the amphibians the hæmal arches are complete only in the caudal region). The next stage in the development of the column is the union of the plates, on the upper and the lower side of the chord, to form a complete cylinder that incloses the chord. The cylinder is of equal bore throughout and does not constrict the chord or tend to divide it up into segments. These two conditions are found only in the most simple of the amphibians and are well illustrated in the immature and mature forms of the *Branchiosauria* (Fig. 1, *A*). The next step is the thickening of the walls of the middle portion of the cylinders that surround the notochord so that the bore is very small at the center, while at the anterior

and the posterior ends the bore is still full size; this tends to divide the notochord at the middle of each vertebra and to leave intervertebral segments. This condition of the vertebræ, with deep cups at each end, is called "biconcave." It is the same condition that is found in the primitive reptiles, and the closing of the notochordal canal and the filling up of either the anterior or the posterior cups of the vertebra would complete the development of the highest type of the reptilian vertebra. (Fig. 1, *B*.)

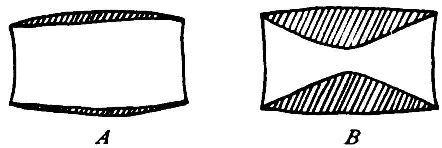
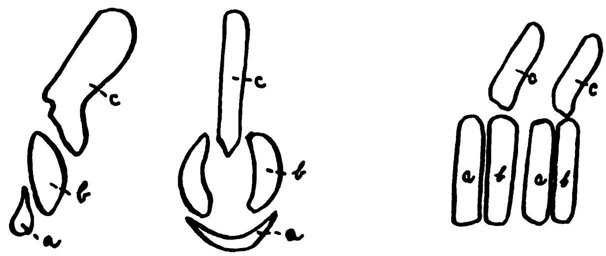


FIG. 1.—*A* Section of Branchiosaurian vertebræ showing size of notochordal canal; *B* Section of microsaurian vertebræ showing contraction of notochordal canal.

Another type of vertebræ that was developed by the amphibians seems to be somewhat more primitive than the last described, and also to be somewhat off the line of direct development. There were four distinct pieces, an upper, that supported the spinuous process, a pair, of small size, that stood on each side of the notochord, the pleura-centra, and a crescent shaped piece on the lower side, the intercentrum, that occupies the position of the plate supporting the hæmal arch in the simpler vertebræ. Upon the condition of these four pieces were established the divisions of the suborder *Labyrinthodonta vera*. When the pieces are all separate and in the condition described above, the forms are called rachitomous; the two lateral pieces may fuse and form a ring around the notochord, and at the same time the intercentrum develop from a crescent-shaped piece into a perfect ring, so that each vertebra is represented by two complete rings, this is the embolomerous stage; in the third condition the four pieces fuse to form a solid vertebra; this is most common in the caudal region and may be present there, while in the anterior portion of the column the

four original pieces are still separate. This is the stereospondylus condition (Fig. 2).

Another line of development that is quite closely connected with the geological history of the animals is the development of



A *B*

FIG. 2.—*A* Rachitomous vertebra. *B* Embolomerous vertebra. *a* Intercentrum; *b* Pleurocentrum; *c* Neural spine.

the shoulder girdle. In the more primitive forms, especially the *Branchiosauria* of the Permian, the bones of the shoulder region were largely cartilaginous and were small in size; as we progress through the Carboniferous and into the Triassic time the bones become larger and firmer, until in the latest of the Triassic forms they form a close dermal armor over the underside of the thoracic cavity. In the majority of the forms there is developed in the skin of the abdomen and the lower side of the legs as well, a large number of small bony ossicles that served as a protection for the posterior part of the body. The history of these is also closely connected with the geological progress of the animal; in the earliest forms the ossicles are small and numerous; as the forms progressed the ossicles became larger and less numerous.

BRANCHIOSAURIA.—This is the most primitive group of the *Amphibia*. The forms were all small and salamandriform; there was a short tail, and the limbs were short and weak. The vertebræ in the adult form were barrel-shaped as already described and in the immature form composed of two separate pieces, an upper and a lower. There was no plication of the enamel of

the teeth as in the more advanced forms. The bones were largely cartilaginous, the tarsus and carpus and the bones of the occipital portion of the skull entirely so. The ventral surface of the body was protected by a large number of dermal scutes.

Most of these forms are known from the Rothliegende of Germany, but specimens have been found from the same horizon and from the Upper Carboniferous of France and Ohio; from the German region a very large number of forms have been taken in the most excellent state of preservation so that it has been possible to study not only the adult forms, but the young stages as well and to make out the various steps in the metamorphosis of the individual. Credner studied a large series of forms from about 30^{mm} to 120^{mm}, and made out all the stages of development, the growth of the external gills, their loss, and the assumption of the adult form.

Branchiosaurus is the best known genus of the suborder and a description of it may serve as an illustration of the whole group. The head was comparatively large and rounded in front; the edges of both jaws were lined with numerous small, conical teeth; the skull was completely roofed by dermal bones, and the surface of these bones show a very strong sculpture. The condition of the vertebræ, the carpus and tarsus, and the bones of the occipital region was as already described; the limb bones were cartilaginous at the extremities. The eyes were rather large and were protected by bony plates developed in the sclerotic coat, the "sclerotic plates." The whole animal must have presented much the same appearance as one of the modern salamanders and had, probably, much the same habits, never going any great distance from the water.

Melanerpeton, *Apateon*, and *Pelosaurus* from the same locality and horizon as the *Branchiosaurus*, were very similar in appearance, differing only in minor skeletal characters.

Protriton is a form described from the Rothliegende of Autun, in France, and is regarded by some as identical with the early stage of *Branchiosaurus* as it has the external gills and other characters of the larval forms of that genus.

Amphibamus and *Pelion* are from the Carboniferous beds of Ohio. In the first genus the body was rather long; the legs were short with the posterior pair somewhat the largest; the head was rather large and rounded; the teeth were numerous and set close together. *Pelion* had a rather shorter and broader head, the legs were longer and better developed.

MICROSAURIA.—These were in many ways the most highly developed of the *Labyrinthodontia;* the vertebræ, as already explained, approached more nearly the modern type of reptilian vertebræ than any of the group. Their advanced position is evidenced by other parts of the body as well as the vertebræ; all the bones of the body are more perfectly ossified; the bones of the skull are set more firmly together, and the limbs are longer and stronger so that the animal was able to raise the body from the ground, and must have possessed a considerable degree of agility. The carpus and tarsus were ossified, and there were well-developed claws on the feet. Many remains have been found in the trunks and stumps of fossil trees in the working of the quarries in the South Joggins coal region of Nova Scotia, showing that the animals were to some extent at least arboreal in their habits, and that they had reached a freedom of motion and a range of habitat far in advance of that of the other amphibians of the time. It is to this group that we must look, in all probability, for the direct ancestors of the reptiles. The name *Sauromorpha* has been given to the group in recognition of the close relation between it and the *Reptilia.*

Hylonomus and *Hylerpeton* are forms from the South Joggins quarries of Nova Scotia. They were rather elongate in form, with a lizard-like appearance. The vertebræ were well developed, and the whole body was covered with bony scutes instead of the ventral surface only as in most of the forms. The teeth were smooth at the base, but near the top the dentine was somewhat plicated. These were among the best developed of the amphibian forms. It is interesting to note the occurrence of the same genus, *Hylonomus,* in Nova Scotia and in Bohemia.

From the Carboniferous rocks of Ohio, near Linton, have

been taken a very large number of the *Microsauria*. Among the most common are *Tuditanus*, *Leptophractus*, *Colosteus*, *Osteocephalus*, and *Ptyonius*.

Tuditanus was rather small form with a short and broad head and the orbits located far forward. There seems to have been a lack of the dermal scutes on the ventral surface and their place was taken by three pectoral shields that exhibit a strong sculpture on the external face; they were the expanded clavicles and the interclavicle. The whole animal was about three to four inches long.

Colosteus reached a length of a foot in some cases. The form was elongate with rather short legs. There were three pectoral plates as in *Tuditanus* as well as a well-developed armor of fine scutes. The teeth were not of equal size, the anterior ones being much the larger.

Ptyonius exhibits a very high degree of specialization. The body was long and serpentiform, and the limbs had entirely disappeared so that the animal had reached the same stage of development as the modern snakes. One very peculiar thing is to be noticed about this form; the distal edges of the transverse processes and neural-spines were fluted or folded so that they present a fan-like appearance.

Leptophractus was by far the largest of the Ohio forms, having about the size of an alligator. Only portions of the skull are known but enough to show that the skull was rather elongate, and that the teeth had the dentine folded as in the true labyrinthodonts. Near the anterior end of the jaw there was a large caniniform tooth.

Osteocephalus resembled in some respects *Ptyonius*. The body was long and snake-like, and the skull was very acuminate. The anterior pair of limbs were absent or rudimentary, and the posterior pair were very short. The three pectoral plates found in most of these forms were absent in this one, and their place was taken by a profusion of slender bony rods that ran obliquely inward and forward covering the whole ventral surface. There were no dermal scutes as in the other forms.

The Carboniferous rocks of Nyran in Bohemia have yielded many forms belonging to the same group, among them are *Hyoplesion*, *Orthacosta*, *Microbrachis*, *Keraterpeton*, and *Urycordylus*.

Hyoplesion is quite similar in structure to *Hylonomus* of the Nova Scotian region, and is regarded by some authorities as synonymous with it.

The other forms do not present any striking peculiarities except *Urycordylus*, which has the same peculiar fluting sculpture of the ends of the transverse processes and the neural-spines as *Ptyonius* and *Osteocephalus* of North America.

AISTOPODA.—This group was very similar in some respects to certain forms of the previous group. The limbs were entirely atrophied as in *Ptyonius;* in addition to this character the parietal and frontal bones were fused into one, and the ribs showed a very peculiar bifurcated condition near the distal end.

Dolichosoma from the Carboniferous rocks of Ireland and Bohemia was quite long, having as many as 150 vertebræ, a number equaled only among the snakes. The skull was small and tapered to a point in front, and there was no evidence of dermal armor.

Ophiderpeton from the Carboniferous of Ireland had a somewhat shorter and broader skull than *Dolichosoma*; the ventral surface of the body was covered with small scutes; the whole animal was about 40–50^{cm} long, and there were in the neighborhood of 100 vertebræ.

Phlegethonia and *Molgophis* are two forms from the same region in Ohio as the *Microsauria* mentioned. They have been considered as synonymous with *Dolichosoma*, which, if true, would indicate a peculiarly wide range for such a specialized form.

LABYRINTHODONTA VERA.—As before stated this group is made up of three subgroups, the *Rachitomi*, the *Embolerimi*, and the *Labyrinthodonti*. The first subgroup is found only in the United States.

RACHITOMI.—In this division, as in the others of the same group, there were many very large forms. The skull was com-

pletely covered with thick and heavy membrane bones that showed a deep and intricate sculpture; the whole head was flattened and either very broad in proportion to its length or long and crocodilian in aspect; the base of the skull was in large part cartilaginous; the limbs were short but very strong, and there were five digits on each foot: the tail was of moderate length; the pelvic and pectoral girdles were strong and broad; the pelvis was peculiarly like that of the modern frog in many of the forms; the vertebræ were made of several distinct pieces as already described. The known forms of the group are almost entirely from the Permian rocks of Europe, the East Indies, and North America.

Archægosaurus from the Rothliegende of Germany was rather crocodilian in aspect; the head was long and slender and joined to a rather elongate body. In youth the animal was furnished with external gills as in the modern salamanders, which were probably shed when the animal reached maturity; the dentine of the teeth was arranged in a radial manner the first step towards the intricate folding of the enamel in the more advanced forms; the clavicles and the interclavicle were broad and strong covering to some extent the lower surface of the thorax.

Chelydosaurus from the Rothliegende of Bohemia was shorter than *Archægosaurus* with a broad head and large orbits; the dermal bones covering the head were sculptured in a peculiar radial fashion. Nearly every portion of the skeleton is known, and the preserved bones show that the animal was rather in advance of the majority of the forms of the time as they are almost entirely free from cartilage.

Discosaurus is a closely related form from the same horizon in the neighborhood of Dresden.

Actinodon and *Euchirosaurus* are from the lower Permian (Rothliegende) of France. The first was much like *Archægosaurus*, but the head was shorter and more triangular in outline; the length of the skull was about 18^{cm}. The second genus is less well known than the first, but is remarkable for the strength

and perfection of the limb bones, especially the articular surfaces which, as a general thing, are not well developed even in the recent amphibians.

Melosaurus from the Keupfer sandstone of Orenbourg in Russia was, so far as the imperfect specimen can be interpreted, quite similar to *Archægosaurus;* it has been suggested that it may be the same genus; if this is true, it would indicate a very wide range of distribution for the animal.

Trimerorachis and *Eryops* are from the Permian deposits of Texas in the United States. Only the lower division of the Permian, the Wichita division of the Texas geologists, has yielded any vertebrate fossils, but in this horizon there is a somewhat abundant fauna of amphibians, reptiles and fishes. In the neighborhood of Danville, in eastern Illinois, there have been found remains of the same amphibians that are found in the Texas deposits; the area is only a small one and is regarded as the course of an old river that has cut its bed through the underlying Carboniferous rocks. Some fragments of the same animals have been found in New Mexico. Of the genus, *Eryops*, Cope, the describer says, "this is the largest of American batrachians, the skull measuring a foot wide by eighteen inches long. It was very abundant constituting with the reptilian genus, *Dimetrodon*, the most prominent type of the Permian fauna in this country. The vertebral column is slender when compared with the size of the limbs and especially the head." Of the genus *Trimerorachis* he says, "the head of *T. insignis* is wide, flat and rounded, and its superior surface is strongly wrinkled. The lyriform mucous grooves do not extend behind the orbits. This was an abundant species during the Permian time in Texas, and probably possessed aquatic habits."

Acheloma and *Anisodexis* are forms from the Permian of Texas that are less well known than the foregoing and are perhaps synonymous with *Eryops*.

EMBOLERIMI.—These are perhaps the most interesting of the *Layrinthodontia*; as already indicated they are distinguished by the fact that the vertebræ are made up of two rings formed by

the upward growth of the lower segment of the vertebra of the rachitomous type and the downward growth of the upper segment and its union with the two lateral segments.

Cricotus, the best known form is from the Permian deposits of Texas, the same locality as the rachitomous forms. It was rather long and crocodilian in aspect and the head was covered with the same kind of membrane plates as in the other genera but they were devoid of sculpture; the orbits were large and placed far forwards.

Diplovertebron from the Gaskohle of Bohemia is known only from fragments of the skull, limb bones and vertebræ, but the vertebræ show the same structure as *Cricotus*.

LABYRINTHODONTI (STEREOSPONDYLI).—These are the very large form that appeared at the end of the Palæozoic and reached their greatest development during the Triassic. They possessed complete biconcave vertebræ with a central foramen for the passage of the notochord. The most peculiar feature of the group, is the arrangement of the outer layer of the teeth; instead of the usual smooth layer the enamel is thrown into the most complicated folds so that a cross section of the tooth has an almost dendritic appearance. In other features than the teeth the group evinces its advanced position among the amphibians; the bones of the skull are all well ossified and the base of the skull is composed entirely of bone instead of being partly cartilaginous as in the preceding groups; there is no trace of the grooves on the upper surface of the skull to mark the position of the sensory tracts; the thoracic region is completely protected by the development of the clavicles and the interclavicle into large and strong plates that are tightly joined together; the posterior abdominal region is also protected by the expansion of the bones of the pelvis though not to the extent reached in the anterior girdle; the limb bones are all well ossified and the carpus and tarsus were entirely bony; the feet were provided with strong claws.

Trematosaurus from the Buntersandstein, near Bernberg, in Germany, was one of the smaller forms; the skull was about

24^{cm} long and rather narrow, giving the skull a rather crocodilian appearance; the edges of the maxillaries were lined with small, nearly equal sized teeth that were opposed to a similar series on the lower jaw; besides the rows of teeth on the maxillaries there were a number of larger teeth on the palatines and the vomer, covering the roof of the mouth with a strong dentition.

Metoposaurus (*Metopias*) from the Keupfer sandstone of Germany was nearly twice as large as *Trematosaurus*, the skull measuring about half a meter. The shape of the skull was much the same as in *Eryops* of the American Permian, being broad and stout, depressed from above downwards and showing a decided sculpture on the outer surface of the bones; the genus is peculiar for the very strong development of the pectoral shields, the interclavicle is a broad, diamond-shaped bone on either side of which are joined the clavicles that are also developed into broad plates, the whole covering the ventral side of the anterior portion of the body; all three of the bones exhibit a rugose outer surface.

Capitosaurus from the same locality and horizon as *Trematosaurus* was nearly as large as *Metoposaurus;* the orbits were small and elliptical; the nares large and located far forward; the extremity of the snout was broad and blunt. The same dentition is found in this as in the previous form, a series of small teeth on the edges of the upper and lower jaws and a few large tusk-like teeth on the palatines and the vomer; the surface of the skull shows a slight trace of the sensory canals and the bones are deeply pitted with grooves radiating outward to the edges of the bone.

Mastodonsaurus from the Lettenkohl, the lower division of the Keupfer, reached the largest size of any of the *Labyrinthodonti;* the skull in some specimens reaching a meter in length. The skull was rather triangular in outline; the eyes were small and the nares located far forwards; the grooves marking the course of the sensory tracts are very distinct; there was a double instead of a single row of small teeth on the edges of the upper and the lower jaws and there were two or more enlarged

palato-vomerine tusks on each side. The whole animal had a probable length of about ten feet, the head being disproportionately large.

Labyrinthodon from the same horizon as the previous forms is, according to Lydekker, a synonym of *Mastodonsaurus*. It was described by Owen from a single tooth and the name was founded on the peculiar folding of the dentine. As most all of the *Labyrinthodonti* have the same character the distinction fails; it is as well however to know the genus as the name is a common one in the text-books. (See Owens, *Odontography*, Pl. LXIII. Fig. 1, for a picture of the structure of the labyrinthodont tooth.)

Nyrania from the Permian of Bohemia and *Bothriceps* and *Micropholis* from the Permian of South Africa are less well known foreign genera. Certain imperfectly preserved remains have been collected from the rocks of the Newark system of Pennsylvania and North Carolina. *Eupelor* is the name of the small form from Pennsylvania, and *Pariosteigus* and *Dictyocephalus* from the Carolina region. Quite recently a tooth has been described from the Upper Carboniferous of Kansas, and referred to the genus *Mastodonsaurus;* if the determination is correct this indicates a rather peculiar distribution for the genus as it is unknown from the English deposits, though quite common on the continent.

Below is a summarized list of the most important forms of the *Labyrinthodontia* with their geological range and habitat so far as known.

LABYRINTHODONTIA.

Branchiosauria.

Branchiosaurus, Rothliegende, Germany.
Melanerpeton, *Apateon* and *Pelosaurus*, Rothliegende, Germany.
Protriton, Rothliegende, France.
Amphibamus and *Pelion*, Carboniferous, Ohio.

Microsauria.

Hylonomus and *Hylerpeton*, Carboniferous, Nova Scotia.
Tuditanus, *Osteocephalus* and *Colosteus*, Carboniferous, Ohio.
Hyoplesion and *Microbrachis*, Carboniferous, Bohemia.
Lepterpeton and *Keraterpeton*, Carboniferous, Ireland.

Dolichosoma and *Ophiderpeton*, Carboniferous, Ireland.
Molgophis? and *Phlegethonia?*, Carboniferous, Ohio.

Labyrinthodonta vera.

Rachitomi.

Archægosaurus, Rothliegende, Germany.
Chelydosaurus, Rothliegende, Bohemia.
Actinodon and *Euchirosaurus*, Rothliegende, France.
Trimerorachis and *Eryops*, Permian, Texas.

Embolerimi.

Cricotus, Permian, Texas.
Diplovertebron, Permian, Gaskohle, Bohemia.

Labyrinthodonti.

Trematosaurus, Buntersandstein, Germany.
Metoposaurus, Keupfer, Germany.
Capitosaurus, Buntersandstein, Germany.
Mastodonsaurus, Keupfer, Germany.
Micropholis and *Bothriceps*, Permian, South Africa.
Eupelor, *Pariosteigus*, and *Dictyocephalus*, Triassic, Pennsylvania, and North Carolina.

Besides the remains of fossil forms the rocks of the Carboniferous and Triassic times have yielded a large number of tracks, made when the animal walked across some mud flat. These tracks have received the name of *Ichnites*. Such tracks in the Carboniferous rocks are known from Kansas and Nova Scotia. Most of the tracks however occur in the Triassic rocks; the red sandstone of the Connecticut River Valley has yielded a large number. Prominent among them is the form described as *Brontozoum*. These are enormous tracks, the middle digit having a length of 12.5 inches and the whole foot 14 to 18 inches. The whole animal must have been twelve to fourteen feet long.

Anisopus from the same locality had the hind foot nearly twice as large as the front foot.

Anomœpus had five digits on the front foot and only three on the hind foot. (This form may very possibly have been reptilian).

Chierotherium or *Chierosaurus* from the Buntersandstein of Europe was about half the size of *Brontozoum*, The hind foot

was about twice the size of the front foot, and there were five digits on both. The same form is known from the Triass of Cheshire in England.

It is altogether probable that many of these tracks belong to forms already described from parts of the skeleton but until some one shall be so fortunate as to discover the skeleton and the tracks together it will be impossible to detect the synonymy. It has been suggested that the tracks referred to as *Cheirosaurus* belong either to *Capitosaurus* or to *Trematosaurus*.

The whole of the order *Labyrithodontia* dies out in the Triassic but the degree of specialization to which the members of the order attained bears ample witness to the important part they played in the fauna of the Carboniferous and the first part of the Mesozoic. Only by the demands of a most severe struggle for existence could there have arisen within the limits of a single order the necessity for the great divergence of forms that we find among the *Labyrinthodontia*. The wide distribution of the forms also bears witness to their prominence, forms being known from the East Indies, South Africa, Europe, England, and North America.

The remaining orders of the amphibians are unknown before the Cretaceous.

The *Caudata* (*Urodela*) are lizard-like, tailed animals with a naked skin and with or without persistent external gills. The skull lacks certain of the bones found in the posterior part of the skull of the *Labyrinthodontia*, as the supratemporal, supraoccipital, and the postorbital. The vertebræ are complete in a single piece. There are two suborders of the *Caudata*, the *Ichthyoidea*, in which the vertebræ are biconcave, and the *Salamandrina*, in which they are opisthocoelus or concave behind and convex in front. The common *Siren*, *Proteus*, and *Menobranchus* are living representatives of this order. Among the fossil forms perhaps the most interesting is the *Andrias* from the fresh water Miocene of Œningen. This form was described as early as 1726 by Scheuchzer, who considered the imperfect skeleton which he had as the remains of an antediluvian man, and gave

to it the name "homo diluvii testis et theoscopos." The same form was afterwards described as fish and as a lizard, until finally its true nature was made out. The form reached a length of about four feet in the largest specimens and was one of the largest of the *Caudata*. In most of its skeletal characters it was very similar to the modern *Menobranchus*.

Megalotriton is one of the *Salamandrina* from the Upper Eocene of France. It was of considerable size, judging from the vertebræ and the detached bones of the limbs. No complete skeleton has been found.

The *Anura* (*Ecaudata*) are little known from the fossil forms. They appear in the Tertiary with almost as many genera and species as at the present time, and there has been little change in the forms.

The origin of the modern forms of the amphibians is not known. Zittel says of these forms that they can in no sense be derived from the labyrinthodonts, for between these and the modern forms there exists not only a great morphological gap, but a great break in the geological record as well.

III. REPTILIA.

PAREIASAURIA.—The simplest of the *Reptilia* differ very little from the *Amphibia*. There is little in the structure of the *Pareiasauria* that might not belong to the *Labyrinthodontia* except the arrangement of the bones forming the base of the skull. Add to this that the animal did not undergo a metamorphosis from a water to a land form and the list of differences is complete. All during the Carboniferous time the conditions had been growing better and better fitted for the existence of purely terrestrial, air-breathing forms, and at the end of that time, if not, as there is reason to think, some time before, there appeared the forerunners of the great tribe of reptiles. As has been indicated, the *Microsauria* were in all probability the direct ancestors of the reptiles, but the evidence of the preserved forms is so incomplete that we do not have either what must have been the

last step of the amphibian line or the first of the reptilian. The development of reptilian forms at the beginning and throughout the Permian time was most remarkable; it seems as if the conditions had been preparing for a long time and with the dawn of the Permian disappeared the last obstruction to the growth of the reptiles which appeared at once in the greatest profusion. Not only were there great numbers of forms, but they were, even in the earliest time that we know them, already highly specialized. The group that is discussed first, the *Pareiasauria*, is nearest to the amphibia in many of its characters, while in others it is one of the most specialized of all the vertebrates. The Permian time has perhaps a larger number of highly and curiously specialized forms than any other time.

In 1840 there was discovered in the Karro formation, Permian or Permo-Triassic, of South Africa, a large number of fossil remains that were shipped to the British Museum, and there described by Professor Owen as a reptile closely related to the dinosaurs, and named by him, *Pareiasaurus bainii.* Later a nearly perfect skeleton was found and described by Professor Seeley, who redescribed the genus and species and placed it in a distinct order, the *Pareiasauria* (1863). As this animal is typical of the whole group it may be described somewhat in detail.

Pareiasaurus was one of the largest as well as one of the most amphibian-like of all the reptiles. The head was covered with large bony plates that had practically the same arrangement as in the *Labyrinthodontia;* the bones formed a complete roof, leaving only five openings in the skull, the orbits, nares, and the pineal foramen; there were traces of the sensory tracts on the surface of the skull, as in the largest of the *Labyrinthodonti;* the teeth were equal in size and distributed all around the edges of both jaws in an even series; there were small teeth arranged in rows on the palatine and the vomer bones in the roof of the mouth; the limbs were short and strong, with well-developed articular surfaces, and the feet were provided with strong claws; there were eighteen presacral vertebræ. This is of considerable

interest, as the number is the same that occurs in the turtles, and this is one of the few clues that we have as to the origin of the turtles. The vertebræ were biconcave, but were not perforated for the passage of the notochord, which was consequently divided into intervertebral segments. In the skin of the back directly over the spinal column there were developed three rows of bony ossicles, the middle row lying directly over the spinous processes and the other two lying upon each side; this development of dermal plates is regarded as the first step toward the formation of a carapace, and as an additional evidence of the connection of the *Pareiasauria* with the turtles. The thoracic girdle is stout and heavy and retains the central element, the interclavicle, which is lost in the majority of the reptiles; the pelvis was large and massive. In life the animal must have presented the appearance of a large amphibian; the legs were too short to lift the body off the ground, so the belly must have dragged as in the crocodiles; the whole body was short and squat and the tail was short; the skin was without scales and was probably thickened and folded.

Scattered bones indicate the presence of at least two other genera, *Propappus* and *Anthodus*, in the South African deposits, but not enough of the skeleton is known to warrant a description. In the American Permian deposits of Texas and Illinois there have been found a large number of forms belonging to this order; the best known are *Diadectes*, *Empedias*, *Chilonyx*, *Pantylus*, and *Pariotichus*.

Diadectes and *Empedias* are the best known of the forms; they are similar to *Pareiasaurus*, though they did not reach the size of that form; they had the same broad, flat skull with few openings; the teeth are different from the African form, in that, although they are similar in size and arranged in regular order around the edges, they are not simple in form, but are expanded laterally so that they exhibit broad grinding surfaces instead of cutting edges; they were undoubtedly herbivorous forms; the number of the presacral vertebræ is unknown, but it was probably greater than in *Pareiasaurus;* the verte-

bræ were greatly flattened in the antero-posterior direction and expanded laterally; this feature, with the short and stout limbs, led Cope to suggest that they were possibly fossorial in habit.

The three remaining forms mentioned have been placed in a separate family from the preceding, the *Pariotichidæ;* they are all smaller than *Diadectes*, never exceeding a length of two or three feet, and are further distinguished by the fact that the teeth are not equal in size in all parts of the jaw, the teeth of the middle part of the maxillary series being larger than the others. Certain of the less well known of the Texas forms show broad bony plates that extend outward from the middle of the back and cover the ribs to a large extent; they correspond to the ribs in number and position. This is a very close approximation to the condition in the turtles; in *Otocœlus* the plates are especially well developed and the lateral edges of adjacent plates meet.

The taxonomy of this group and its related forms is very imperfectly understood and there has resulted little but confusion from the numerous schemes of classification that have been proposed. When the first of the African fossils were discovered and described the name *Anomodontia* was proposed by Owen for the whole series of African forms, as he supposed that they were all closely related, but he soon recognized that this was not true and separated a group, the *Theriodontia*, to include the forms with a more carnivorous dentition. Later writers have found it necessary to depart very widely from this scheme and have founded new orders and in some cases done away with the original ones. Out of this tangle one thing seems very clear, the order *Pareiasauria* is a distinct order separate from all the rest of the Permian reptiles and is the primitive form of all the reptiles. Other forms that are closely related to this order, but whose structure is too incompletely known to make the determination of their position definite, had best here be retained in the original order *Anomodontia* as suggested by Seeley and Lydekker. The classification of the forms will then stand as follows :

Order *Pareiasauria*.
Fam. *Pareiasauridae* (African forms).
Diadectidae (American forms).
Pariotichidae (American forms).
Elginidae (European forms).[1]
Order *Anomodontia*.
Suborder *Dicynodontia*.
Placodontia.
Theriodontia.

The *Dicynodontia*, including the genera *Dicynodon*, *Oudenodon*, and *Ptychosiagum* (*Ptychognathus*), are all from the same locality, South Africa, as *Pareiasaurus*, and from the same geological horizon.

Dicynodon is known only from the skull and is one of the most peculiar of the reptilian forms; the jaws were edentulous except for the presence of two large tusk-like teeth that grew out from the anterior part of the upper jaw just in the position occupied by the canine teeth in the mammals; the part of the upper jaw anterior to these teeth and the lower jaw were protected by a horny sheet similar to that present in the turtles; the posterior part of the skull was perforated by large fossae that served to lighten it considerably. This process of lightening the skull by the development of large fossae in the posterior, temporal portion, is a constant feature of all the reptiles above the *Pareiasauria* with the exception of the turtles. Many scattered bones have been found in the same deposits as the skulls of *Dicynodon* that may belong to the same genus, but there is not sufficient evidence to say definitely that this is true, and until the vertebral column and the limb bones are made out it

[1] *Elginia* is an imperfectly known form from the Elgin (Triassic) sandstones of Scotland. There are no bones preserved, but only the impression of the bones in the soft sandstone from which all the bony tissue has rotted out. The fossils were studied from casts made of the cavities left by the decayed bones. The animal was of considerable size, nearly as large as *Pareiasaurus* and the teeth were arranged in a regular series around the edges of the jaws; the appearance of the skull in life must have been most peculiar, the presence of strong rugosities on the surface of the bones of the skull show that the head was covered with large horns. *Geikia* was a related form from the same locality and horizon.

will be impossible to determine accurately their position with relation to the other reptiles.

Oudenodon was also described from the skull alone; the jaws are entirely edentulous and the appearance of the skull is strikingly testudinate. It has been suggested that this is the female of *Dicynodon*.

Ptychosiagum, or as it is more generally known, *Ptychognathus*, was very similar in many respects to the *Dicynodon*, having the same horny covering to the anterior portion of the jaws and the large canine teeth in the upper jaw; the peculiar part about the animal was the bending of the facial portion at almost a right angle to the upper surface of the skull and the upward extension of the anterior end of the lower jaw so that the mouth seemed to open on the superior face of the skull.

All of these animals must have been herbivorous; the large canine teeth were probably used to tear up the roots and aquatic plants upon which they fed. They could have been of no use as organs of offense or defense.

Placodontia.—These are rather problematical forms from the Muschelkalk (Triassic) of Germany. As in the case of the *Dicynodontia* the bones are all isolated and the various genera are known from the skulls; the few other bones that have been found in the same deposits may or may not belong with the skulls. Lydekker has called attention to the fact that all the bones that are found with the skulls are either dinosaurian or plesiosaurian; if it should turn out that the plesiosaurian bones belong with the skulls of the Placodontia it may be that that group belongs very far from the *Anomodontia* with which they are here placed, but until that is established it is perhaps best to take the evidence of the skull which points to a very decided relationship between the two groups. *Placodus* and *Cyamodus* are the two described genera.

Placodus was first described by Agassiz from a single tooth, and was regarded by him as a fish. The error was not corrected until the entire skull of the form was known. The skull was triangular in outline, very broad behind and rapidly narrowing

to a pointed rostrum in front; the orbits were large and the anterior nares very small; the posterior part of the skull shows the presence of the fossae already mentioned. The teeth are the most striking features of the skull, the anterior incisors were chisel-like and prehensile; the maxillaries were broad and flat; there were five on each side; besides the maxillary teeth there were three large palatine teeth on each side, so large that they covered nearly the whole roof of the mouth. The broad, low teeth of both this and the succeeding forms seem to indicate that the animals were accustomed to a molluscan diet.

Cyamodus was very similar to *Placodus*, but there were no prehensile incisor teeth and there were five palatine teeth, the posterior pair far exceeding the anterior ones in size.

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EDITORIAL.

IT would seem that there may be need to select for technical use suitable terms to specifically designate the critical factors of the sea border phenomena described in the first article of this issue. At least three agencies coöperate in producing a structural and topographic form which has a vital geologic function, and to which specific reference may frequently need to be made without descriptive circumlocution. The same may be said of some of the contributory factors and processes involved. The functions of these are more or less masked, and even antagonized, by adventitious phenomena which need to be distinguished and excluded. (1) There is first the building of the sediments into a submarine terrace. The plane toward which this terrace is built up is identical with that toward which the land is cut down. The two processes are complementary. The degradation of the one furnishes the material for the aggradation of the other, and their final result is a base-plain continuous with a terrace plain, both alike determined by the sea level. As the former process is called baseleveling, the latter might be designated base-terracing and the result a base-terrace, but these terms are not altogether felicitous, because *base* inevitably carries the idea of something beneath rather than above, and cannot perhaps easily be made to convey the conception of an overlying plain to which aggradation approaches, and in which it finds its summit limit. A happy term for a summit plain to which aggradation is limited just as degradation is limited to a base-plain does not as yet suggest itself. (2) There is next the cutting landward of the sea edge, whereby the sea shelf is extended at the expense of the land. This is essentially a baseleveling process, and as such perhaps needs no other term than baseleveling, except as qualifiers may occasionally be required to indicate the particular mode of its action. (3) Then there

is the lifting of the sea surface, whether by filling, by the spreading of the continent in its slow movement towards isostatic equilibrium, or by changes in the sea bottom. The effects in any case are essentially the same, and are world-wide by reason of the common level maintained by the ocean in all its parts. This sea lifting combines with and modifies both the terrace building and the shore cutting, and the common result is a shelf occupied by a shallow sea. This shelf is the great theater of sedimentation and of littoral life evolution. Its peculiar configuration, by giving great breadth to the shallow water circum-continental seas upon a slight lifting of the sea level, or after the erosion and terrace building of prolonged quiescence, on the one hand, and by narrowing these shallow seas to mere fringing ribbons upon the drawing away of the sea until its shore stands against the abysmal edge of the shelf, on the other, makes it a vital factor in geological progress and gives occasion for a specific designation.

It is, however, desirable to exclude those areas that become submerged by their own individual movements and take on the similitude of submarine terraces without having any genetic or systematic relation to the sea level as such. They may stand at such depth as to give an expansion of shallow water just when the withdrawal of the sea narrows the shallow water tract on the true genetic shelf, and thus they may antagonize the evolutionary effects of the latter upon littoral life. They may, to be sure, coincide so nearly with the true shelf in position as to work concurrently with it and increase its effects, but this, from the nature of the case, will rather be the exception than the rule. Such adventitiously submerged portions of the continent must be regarded as factors that vitiate the ideal workings of the true sea-generated terrace.

Both the true sea-formed terrace and the continental border submerged by subsidence are at present embraced without distinction under the phrase "continental shelf"—a designation that fairly represents the topographic fact, but does not carry with it any specific idea of the diverse agencies involved in its

production or their opposed evolutionary functions. It does not discriminate between those features which are coöperative and world-wide, on the one hand, and those which are local and adventitious on the other.

Several terms are used tentatively in the indicated article to designate the true sea-generated terrace. Of these "circum-continental terrace," "pericoastal terrace," and "peripheral terrace" are neither brief nor especially euphonious, and only partially imply the most important relationships of the formation. The term "sea shelf" is in many respects suitable, as it indicates the configuration, in a measure, and implies, or is susceptible of implying, adaptation to the reception of sediments and to the support of littoral life — the two most vital functions which it is desired to express; but it is not clear that the phrase is sufficiently different from the already adopted "continental shelf" to make it easy to develop a technical distinction in its usage. It has, however, the merit of implying a general and not a limited phenomenon, as is somewhat obscurely suggested in "continental shelf." This general sense is peculiarly appropriate, since the terrace is as universal (at least in its initial stages) as the sea border, and is a necessary consequence of the relations of sea and land. It may, perhaps, be best to use the universal term "sea shelf" for the true genetic phases of the submarine terrace, and to leave "continental shelf" to be used in its present undifferentiated application to the submerged border of a continent without regard to its specific genesis. But this suggestion is made with the most tentative intent.

The matter is here discussed not to propose a name for acceptance, but with the quite opposite purpose of filing a caveat in behalf of a free consideration of the merits of terms and a provisional use of them until experience shall bring into clear realization precisely what needs to be named and what terms best supply the need. The basal idea of the doctrine of multiple working hypotheses is applicable to nomenclature as well as geologic theory, and its use here is suggested. The subject is believed to have sufficient importance to justify it. T. C. C.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.[1]

HOVEY,[2] in notes on the Isles of Shoals, of Maine and New Hampshire, states that the general rock constituting these isles is granitic, varying in color from white to black, and that this is cut by later dikes.

Hitchcock, C. H.,[3] gives a general account of the geology of New Hampshire, including a sketch of the work and conclusions of the first and second New Hampshire state surveys and of subsequent workers in the field. Some of the modifications indicated by work done since the close of the second state survey are: (1) Archean rocks exist as oval areas in the Stamford gneiss and south of Mt. Killington, Vt., in the Hinsdale, Mass., area, the Hoosac Mountain, and elsewhere. (2) The masses of Bethlehem gneiss are batholites, with inclusions of adjacent mica-schists. (3) A study of several areas of hornblende-schist proves that they are igneous.

Daly[4] discusses the porphyritic gneiss of New Hampshire, and concludes that it is an eruptive porphyritic granite, at least in its three most important areas, of post-Devonian age.

Cushing[5] mentions pre-Cambrian rocks in Saranac township and Beekmantown, N. Y. These comprise gneisses and gabbro, upon which the Cambrian rests unconformably.

[1] Continued from page 756, Vol. IV., JOUR. GEOL.
The summaries of current pre-Cambrian literature which have heretofore been made by C. R. Van Hise will be continued by C. K. Leith.

[2] Geological notes on the Isles of Shoals, by H. C. HOVEY (Abstract): Proc. Am. Assoc. Adv. Sci., for 44th meeting, 1895, pp. 136, 137.

[3] The geology of New Hampshire, by C. H. HITCHCOCK: JOUR. GEOL., Vol. 4, 1896, pp. 44–62.

[4] Studies on the so-called Porphyritic Gneiss of New Hampshire, by R. A. DALY: JOUR. GEOL., Vol. 5, 1897, pp. 684–722, 776–794.

[5] Geology of Clinton county, N. Y. (preliminary), by H. P. CUSHING: Report of the State Geologist of New York for 1893, pp. 475–489.

Cushing[1] argues the existence of pre-Cambrian as well as post-Ordovician dikes in the Adirondacks and along Lake Champlain, offering the following reasons: (1) A much larger number of dikes occur in the pre-Cambrian than in the Paleozoic rocks. (2) A great proportion of the dikes are of diabase, while diabase rocks are not found outside of the pre-Cambrian areas. (3) Along the line of contact of the Potsdam with the older rocks north of the Adirondacks, the plentiful diabase dikes in the older rocks are apparently cut off by the Potsdam.

White[2] describes and maps the geology of Essex and Willsboro' townships, Essex county, N. Y. The Archean rocks of the townships comprise the following: (1) Labradorite rocks, gabbros, norites, and anorthosites, occupying the western half ot the area, west of the Boquet River; (2) the metamorphic crystalline limestones and ophicalcites in the northeastern part of the area on Willsboro' Bay, and in the southeastern part of the area on the ridge of Split Rock Point; (3) gneisses and granites, chiefly on Split Rock Point. Following Adams,[3] all of these rocks are classed as Norian or Upper Laurentian.

Kemp[4] describes the geology of Essex county, N. Y. The pre-Cambrian succession in this county is as follows: (1) A gneissic series consisting of red and gray orthoclase gneisses, usually laminated, but at times rather massive. In these gneisses are the workable iron ores of the Adirondacks. (2) Apparently resting on (1), a series of crystalline limestones, ophicalcites, black hornblendic pyroxenic schists, and thinly laminated garnetiferous gneiss. Pegmatite veins are a frequent associate of these rocks. (3) A series of rocks of the gabbro family, ranging from aggregates of labradorite through

[1] On the existence of pre-Cambrian and post-Ordovician trap dikes in the Adirondacks, by H. P. CUSHING: Trans. N. Y. Acad. Sci., Vol. 15, 1896, pp. 248–252.

[2] The geology of Essex and Willsboro' townships, Essex county, N. Y., by T. G. WHITE: Trans. N. Y. Acad. Sci., Vol. 13, 1894, pp. 214–233, Pls. VI and VII.

[3] Ueber das Norian oder Ober-Laurentian von Canada, F. D. ADAMS: Neues Jahrb., B. B. VIII, p. 423.

[4] J. F. KEMP: Geology of Essex county (preliminary). Report of State Geologist of New York for 1893, pp. 433–472. See also The Geology of Moriah and Westport townships, Essex county, N. Y. Bull. N. Y. State Museum, Vol. 3, 1895, pp. 325–351. With a geological map.

varieties with increasing amounts of bisilicates to basic olivine gabbros. The gabbros vary from massive to gneissoid rocks which are difficult to discriminate from some of the gneisses of series 1. These rocks contain the titaniferous iron ores. They are intrusive in series 1 and 2. Resting unconformably upon 1, 2, and 3 is the Potsdam sandstone.

Kemp[1] describes the geology of the magnetites near Port Henry, N. Y., and especially those of Mineville in the Adirondacks of New York. The oldest rocks present in the district are quartzose gneisses and white crystalline limestones, with perhaps some more basic gneisses. The limestones appear to lie largely in the upper part of this group, but some of them are certainly below the other members. The acidic gneisses may have been granites or quartz-diorites. The gneiss and limestone group is cut by anorthosite intrusives, and both are in turn cut by gabbro intrusives. Trap dikes, usually of small width, are very common in this district. The age of these dikes is undetermined, but it seems probable that they may be of two ages, pre-Potsdam and post-Utica. Overlying unconformably all of the above described rocks is the Potsdam sandstone.

Darton[2] describes and maps the faulted region of Herkimer, Fulton, Montgomery, and Saratoga counties, New York. Laurentian rocks occupy the northern part of the area, forming the floor for a succession of sandstones, limestones, and shales, which dip to the south at a very moderate angle.

Kemp[3] describes the East River and Blackwell's Island section made by an underground tunnel at 70th street, New York City. Under the west channel is a fine grained mica-gneiss, containing pegmatite seams. Under Blackwell's Island and the adjacent waters is a gray gneiss. In the center of the east channel is a dolomite,

[1] The geology of the magnetites near Port Henry, N. Y., and especially those of Mineville, by J. F. KEMP: Trans. Am. Inst. Min. Engineers, Chicago meeting, Feb. 1897, p. 58.

[2] A preliminary description of the faulted region of Herkimer, Fulton, Montgomery, and Saratoga counties, by N. H. DARTON: 14th Ann. Rept. Geol. Survey of New York, for 1894, pp. 31–56, 1896. With geological map. Published in the 48th Ann. Rept. N. Y. State Museum, 1895.

[3] The geological section of the East River at 70th Street, New York, by J. F. KEMP: Trans. N. Y. Acad. Sci., Vol. 14, 1895, pp. 273–276.

which is flanked on the east side by mica-schist, locally pegmatized. Beyond the mica-schist on the Ravenswood shore is a massive hornblende-gneiss or granite, which is thought to be intrusive.

Merrill,[1] in connection with a report on the mineral resources of New York, publishes a geological map of the entire state and a large scale geological map of the southeastern part of the state. These maps embody information available to date concerning the distribution of the pre-Cambrian rocks of New York.

Merrill,[2] in connection with a report on road materials of New York, publishes a map of the state showing distribution of pre-Cambrian rocks.

Bascom[3] describes and maps pre-Cambrian volcanic rocks of South Mountain, Pennsylvania. The volcanic rocks are both basic and acid. The acid rocks comprise quartz-porphyries, devitrified rhyolites or aporhyolites, with accompanying pyroclastics, and sericite-schists, the last being the metamorphosed forms of the quartz-porphyries and aporhyolites. The basic rocks comprise melaphyres, augite-porphyrites, slates, and pyroclastics. Lithologically the volcanic rocks resemble the Keweenawan copper-bearing rocks of Lake Superior.

There is not sufficient evidence to decide the comparative age of the basic and acid rocks, but field observations in the Monterey district indicate that the acid rocks are the older. The volcanics are overlain, with stratigraphical unconformity, but with structural conformity, by sedimentary rocks of Lower Cambrian age. Both volcanics and sedimentaries have been subjected to strong dynamic action, whereby the igneous rocks have been cleaved and sheared, and the sedimentary rocks thrust over them from the east.

Kemp[4] describes the ore deposits at Franklin Furnace and Ogdensburg, N. J., and briefly sketches the general geology of the area. The

[1] Mineral resources of New York State, by F. J. H. MERRILL: Bull. N. Y. State Museum, Vol. 3, No. 15, 1895, pp. 365–595.

[2] Bull. N. Y. State Museum, Vol. 4, No. 17, 1897, pp. 90–134. With maps.

[3] The ancient volcanic rocks of South Mountain, Pa., by FLORENCE BASCOM: Bull. U. S. Geol. Surv., No. 136, 1896, pp. 124. With geol. map.

[4] The ore deposits at Franklin Furnace and Ogdensburg, N. J., by J. F. KEMP: Trans. N. Y. Acad. Sci., Vol. 13, 1893, pp. 76–98.

ore deposits occur in white crystalline limestone, which is cut in numerous places by dikes of granite, trap, and a rock taken to be altered gabbro. The white limestone is closely involved throughout its extent with a blue limestone of Cambrian or Cambro-Silurian age.

Wolff[1] briefly describes the eruptive rocks of Sussex county, New Jersey, with reference to their economic value. These include granite, elaeolite-syenite, elaeolite-porphyry, and camptonite, and are treated under the head of Archean.

Westgate[2] describes and maps the geology of the northern part of Jenny Jump Mountain, in Warren county, N. J. The main ridge of the mountain is formed chiefly of gneisses, comprising many varieties. These are, from northwest to southeast, and also, according to the banding, from base to top (1) granitoid-biotite-hornblende-gneiss, containing narrow bands of biotite-hornblende-gneiss; (2) hornblende-pyroxene-gneiss; (3) biotite-gneiss; (4) dark biotite-hornblende-gneiss; (5) granitoid-biotite-hornblende-gneiss; and (6) dark biotite-hornblende-gneiss, and gray micaceous gneiss. Certain of the dark hornblende-gneisses have been so extensively altered as to be called epidote rocks. The gneisses are in general granitoid and massive, and there is a conspicuous absence of schistose rocks and crumpling of the banding, the banding over wide areas having uniform strike and dip.

Along the southeast side of the mountain, at the northeast end of the mountain, and in two isolated outcrops within the gneisses of the main ridge, are areas of white crystalline limestone. The limestone is in all cases closely associated, and perhaps interbanded, with the dark biotite-hornblende-gneiss and gray micaceous gneiss (Nos. 4 and 6 above), and at the northeast end of the mountain also with quartz-pyroxene rock.

Cutting both gneisses and limestone are pegmatite, diabase, and amphibolite or granular diorite.

The origin and age of the gneisses are doubtful. The presence of limestone belts closely associated, and perhaps interbanded with the

[1] Report on Archean geology, by J. E. WOLFF: Ann. Rept. Geol. Surv. New Jersey, 1896, pp. 91–94. With map.

[2] The geology of the northern part of Jenny Jump Mountain, in Warren county, N. J., by LEWIS C. WESTGATE: Geol. Surv. of New Jersey, Ann. Rept. for 1895, pp 21–61, 1896. With geol. map.

hornblendic and micaceous gneisses, and the presence of magnetic iron ore, suggest a detrital origin for at least a part of the gneisses, and consequently their reference to the Algonkian. There may be really two series of rocks: (1) A series of limestone and associated interbedded rocks, of sedimentary origin, and (2) a series of more massive granitoid gneisses, probably older, and of unknown origin. This supposition is based only on the fact that the limestones are persistently associated with the hornblendic and micaceous gneisses and quartz-pyroxene rock, and are not found associated or in contact with the light colored granitoid gneisses which constitute the main mass of the mountain. However, there is not sufficient evidence to refer a a part of the gneisses to the Algonkian, and all are therefore classed as pre-Cambrian.

The crystalline limestones are believed to be distinct from and older than the blue magnesian limestone of Cambrian age, which occurs along the northwestern side of the New Jersey Highlands, and and which outcrops in isolated areas in the valleys adjacent to Jenny Jump Mountain, for the following reasons:

1. They differ lithologically from the blue limestone in being thoroughly crystalline, and in containing large amounts of accessory metamorphic minerals, showing that they have been subjected to general metamorphic forces of which the neighboring blue limestone shows no trace.

2. They occur in intimate association with the gneisses, which are of admitted pre-Cambrian age.

3. They show no intimate association in areal distribution with the blue limestone, nor any tendency to grade into it.

4. The metamorphic changes to which the white limestones have been subjected are general in their nature, and not due to the action of eruptives by which they are cut; so that no sufficient agent is at hand to account for the supposed change from blue into white limestone. The white crystalline limestones are therefore believed to be of pre-Cambrian age.

Williams and Clark[1] describe and map the geology and physical features of Maryland. The pre-Cambrian rocks, described by Williams,

[1] Geology and physical features of Maryland, by G. H. WILLIAMS and WM. B. CLARK: Extract from World's Fair Book on Maryland, Baltimore, 1893, pp. 1–67. With map.

form the eastern or holocrystalline division of the Piedmont Plateau region of Maryland, crossing the state in a general southwest direction from the southeast corner of Pennsylvania and the north end of Delaware. These rocks are but a part of the great crystalline plateau which extends from New York to Alabama along the eastern base of the Appalachians. Towards the east the pre-Cambrian rocks of Maryland plunge under Coastal Plain deposits, and toward the west they form the floor to support the Paleozoic strata of the Appalachians, reappearing in the granitic and volcanic rocks of South Mountain of Pennsylvania. The holocrystalline rocks are divisible into six types, three of which, gabbro, peridotite or pyroxenite, and granite, are of undoubted eruptive origin, and three of which, gneiss, marble, and quartz-schist, while showing no certain evidence of clastic structure, are believed to be sedimentary. The prevailing rock is gneiss, closely associated with marbles and quartz-schists, forming an intricate complex. The complex shows evidence of great dynamic action, the rocks, having been almost completely recrystallized. The eruptive rocks are all younger than the gneisses. The gabbro is the oldest, followed by the peridotite or pyroxenite, and the youngest is the granite. The granites are as a rule medium-grained biotite-granites, but they frequently take the form of pegmatite.

Williams[1] considers the general relations of the granitic rocks in the Middle Atlantic Piedmont Plateau and maps the same. The criteria by which ancient plutonic rocks in highly metamorphosed terranes may be recognized comprise radiating dikes, inclusions of fragments, contact zones, chemical composition, and petrographical structure. On these criteria it is concluded that most of the granitic rocks of Maryland are igneous, although many of them are changed to granite-gneiss, and of certain of these gneisses it cannot be asserted whether they are of aqueous or of igneous origin. South of Laurel, in the large area from Triadelphia southward to Brookville, at Murdoch Mill west of Washington, south of Falls Church in Fairfax county, Va., and at Cabin John Bridge on the Potomac River, there are gradations between granitic rocks and diorites or gabbros. In the Maryland

[1] General relations of the granitic rocks in the Middle Atlantic Piedmont Plateau, by GEORGE H. WILLIAMS. Introduction to Origin and Relations of Central Maryland Granites, C.R. KEYES, Fifteenth Ann. Rept., U. S. Geol. Surv., 1895, pp. 659-684, Pls. XXVII-XXXV.

rocks pegmatites are abundant. Some of these are, as indicated by their association with quartz veins and by parallel banding, water segregations. The majority, however, are igneous, as is shown by all of the phenomena of intrusive rocks.

Comments.—The description and discussion of the origin of the pegmatites are of great interest. From the descriptions it is clear, although Dr. Williams does not definitely say so, that there are nearly all gradations from material which is plainly a vein quartz deposit, through others where we have quartz and feldspar with a banded arrangement, and are water segregations, to the pegmatites which have distinct igneous characteristics. This region thus affords a beautiful illustration of Van Hise's[1] conclusion that under proper conditions water and liquid rock are miscible in all proportions, and that pegmatization comprises water impregnation, true igneous injection, and all intermediate processes.

Clark[2] describes the geology and physical features of Maryland. This account is essentially the same as that published by Williams and Clark[3] in 1893, and previously reviewed. Here, however, the crystalline rocks are classed as Archean and Algonkian, both of which are included under the general term Archean. The statement is made that there is no positive evidence that there are represented in Maryland rocks of the earliest portion of Archean time (meaning Archean proper), although a part of the gneiss complex may represent it. The Algonkian period, however, is represented by many varieties of rock. The rapidity with which the crystalline rocks furnished sediments for the overlying formations points to their high elevation in Archean time.

In the western division of the Piedmont Plateau region of Maryland, Algonkian rocks are present infolded with the Paleozoic deposits of Montgomery, Frederick, and Carroll counties. They consist of a single type resembling the metamorphosed basic volcanic rocks (Catoctin schist) of the Blue Ridge district.

[1] Principles of North American pre-Cambrian geology, by C. R. Van Hise: 16th Ann. Rept. U. S. Geol. Surv., 1894–5 pp. 686–688.

[2] The physical features of Maryland, including the physiography, geology, and mineral resources, by Wm. B. Clark: Maryland Geol. Survey, preliminary publication of Vol. 1, Pt. III, 1897, pp. 95. With map.

[3] Geology and Physical Features of Maryland, by G. H. Williams and Wm. B. Clark. Extract from World's Fair Book on Maryland; Baltimore, 1893.

Comments.—The use of the term *Archean* in two senses is objectionable. If it is used for all rocks older than the Cambrian, then another name should be applied to the basal complex. If, following the usage of the U. S. Geol. Survey, Archean is confined to the basal complex unconformably below the Algonkian, the general term for all rocks below the Cambrian should be *pre-Cambrian*.

Clark[1] describes the physical features and geology of Maryland, and gives a sketch of the development of knowledge concerning them. The description of pre-Cambrian geology is essentially the same as that given by Clark in a preliminary publication of this part of the volume,[2] and this in turn is but slightly different from an account given by Williams and Clark in 1893. Both of these articles are reviewed above. However, a few minor changes may be noted. The crystalline rocks of the Piedmont Plateau region, instead of being divided into six types as before, are divided, into seven typesdiorite being added to the list. Rocks of the Archean period are placed in the table of formations as doubtfully present.

Keyes[3] gives a detailed petrographical description of the Maryland granites. For reasons the same as given by Williams they are regarded as eruptive, and many of the gneisses are shown to be dynamically metamorphosed granites.

Darton[4] maps and describes the geology of the Fredericksburg sheet of Virginia and Maryland. He finds in the northwest and west parts that granite, gneiss, and schist occur, and in the northwest

[1] WM. B. CLARK: Outline of present knowledge of the physical features of Maryland, embracing an account of the physiography, geology, and mineral resources; Maryland Geol. Survey, Vol. I, Pt. III, 1897, pp. 139–228; Historical Sketch, Pt. II, *ibid.*, pp. 43–138. With map.

[2] The physical features of Maryland, preliminary publication of Vol. I, Pt. II, 1897.

Geology and physical features of Maryland, by G. H. WILLIAMS and WM. B. CLARK. Extract from World's Fair Book on Maryland; Baltimore, 1893.

[3] Origin and Relations of Central Maryland Granites, by C. R. KEYES, with an Introduction on the General Relations of the Granitic Rocks in the Middle Atlantic Piedmont Plateau, by G. H. WILLIAMS. Fifteenth Ann. Rep. U. S. Geol. Surv., 1895, pp. 685–740. Pls. XXXVI–XLVIII.

[4] Geol. Atlas of the U. S., Fredericksburg Folio, No. 13, by N. H. DARTON: U. S. Geol. Surv., Washington, 1894.

part of the area a belt of rock called the Quantico slate. This slate locally appears to grade into siliceous mica-schist or gneiss. It is about three-quarters of a mile in width, and strikes northeast and southwest. The granite, gneiss, and schist are regarded as pre-Cambrian. The slates resemble the roofing slates on James River, which carry Lower Silurian fossils.

Kimball[1] describes the magnetite belt at Cranberry, N. C., and indicates the mode of development of the magnetite. The ore belt occurs in the crystalline schists forming Cranberry Ridge. These schists are mostly basic, pyroxene and amphibole prevailing. It is suggested that they are of Algonkian age.

Keith[2] maps and describes the geology of the Knoxville quadrangle of Tennessee and North Carolina, and of the Loudon quadrangle of Tennessee. Ocoee rocks form the mountain areas. From the base upward the series comprises the Wilhite slate, the Citico conglomerate, the Pigeon slate, the Cades conglomerate, the Thunderhead conglomerate, the Hazel slate, and the Clingman conglomerate.

The Wilhite slate is bluish-gray or black argillaceous slate. In its upper portion it becomes calcareous, and contains frequent beds of limestone and limestone conglomerate. The thickness is ordinarily from 300 to 400 feet. The Citico conglomerate is entirely siliceous, and varies from fine white sandstone to coarse quartz conglomerate, with a few thin beds of sandy shale. The Pigeon slate is mainly an argillaceous slate of great uniformity, occasionally banded by thin seams of coarser siliceous material. The thickness varies from 1300 to 1700 feet.

The Cades conglomerate, the Thunderhead conglomerate, the Hazel slate, and the Clingman conglomerate, are not described for the Loudon quadrangle.

For the Knoxville quadrangle the Cades conglomerate consists of thick beds of slate, sandstone, graywacke, and conglomerate. The

[1] The magnetite belt of Cranberry, N. C., by J. P. KIMBALL: Am. Geol., Vol. 20, 1897, pp. 299–312.

[2] Geol. Atlas of the U. S., Knoxville folio, No. 16, by ARTHUR KEITH: U. S., Geol. Surv., Washington, 1895.

Ibid., London folio, No. 25, 1896.

apparent thickness is 2400 feet, and this may be an overestimate, because the formation may be repeated by folding. The Thunderhead conglomerate consists of a series of conglomerates, graywackes, and sandstones, with many small beds of slate. The thickness is believed to be about 3000 feet. The Hazel slate is chiefly a black slate, but it contains many thin beds of sandstone and conglomerate in small quantity. The exact thickness cannot be ascertained, but it is believed to be about 700 feet. The Clingman conglomerate is the same in composition as the Thunderhead conglomerate, except that in the Clingman conglomerate there is smaller development of slate beds.

The age of the Ocoee rocks is undetermined, and they are therefore mapped as of unknown age.

Hayes[1] maps and describes the geology of the Cleveland quadrangle of Tennessee. Ocoee rocks occupy the southeastern part of the quadrangle, forming Big Frog Mountain and the plateau along its western base. No fossils have yet been found in these rocks, and they are separated by a great fault from rocks of known age, so that their position in the stratigraphic column cannot be fixed with certainty, but since they bear the marks of extreme age, they are considered as probably Algonkian. The Ocoee series comprises in this area the following formations, from the base upward: the Wilhite slate, the Citico conglomerate, the Pigeon slate, and the Thunderhead conglomerate and slate. Their correlation with formations bearing the same names in the Knoxville quadrangle to the northeast, described by Keith, is only approximate. The Wilhite slate consist in the main of dark blue or black slate. The Citico conglomerate varies from a coarse, massive conglomerate to fine grained sandstone or quartzite in sandy shale. The thickness varies from 500 to 1150 or more feet. The Pigeon slate resembles the Wilhite slate, the chief difference being a frequently observed banding and an abundance of interbedded gray schistose sandstones and graywackes, and occasional conglomerates. The Thunderhead conglomerate and slate can be separated into three divisions. The lowest of these, from 800 to 1000 feet thick, is a massively bedded conglomerate, made up largely of blue quartz and feldspar pebbles. The middle division consists of interbedded black slate and schistose conglomerate or sandstone, the slate apparently

[1] Geol. Atlas of the U. S., Cleveland folio, No. 20, by C. W. HAYES: U. S. Geol. Surv., Washington, 1895.

predominating. The upper division is also composed of conglomerate and slate, but the slate is comparatively unimportant.

King[1] describes the geology of the "Crystalline Belt" of Georgia, in connection with the occurrence of corundum. The Crystalline Belt occupies an area of 12,430 square miles, crossing the northern part of Georgia from the northeast to the southwest, and lying between Paleozoic strata in the northwest corner of the state, and Mesozoic and Cenozoic strata in the southern half of the state.

The rocks of the Crystalline Belt are divisable into two petrographical classes. The first consists of a series of mica-schists, slates, shales, conglomerate, and marble, which, though more or less crystalline, show evidence of clastic character. This class is called the *semicrystalline* series. The semicrystalline rocks are confined to an area bordering the Paleozoic to the northwest. The second class comprises eight types of rock. Three of them, limestone, quartzite, and slate, are undoubtedly clastic; three of them, granite, gneiss, and mica-schist, are completely crystalline and show no trace of clastic character; and two, peridotite, and diorite, are presumably of eruptive origin. Gneiss and mica-schist are the prevailing rocks. This second class is termed the *holocrystalline* series.

The rocks of the Crystalline Belt are separated from the Paleozoics on the northwest by a strong unconformity. Between the semicrystalline and holocrystalline rocks there is apparent transition.

Throughout the Crystalline Belt there is a uniform dip to the southeast, pointing toward a moving force from the southeast, but in the holo-crystalline area the dip is much steeper than in the semicrystalline area. Disturbances and alterations are more extensive in the holocrystalline rocks than in the semicrystalline rocks. Corundum is present only in the holocrystalline rocks.

From these facts it is believed that the holocrystalline area is older than the semicrystalline area, and formed the continent against which washed the waters of the sea which deposited the rocks of the semicrystalline series. While a portion of the holocrystalline series may be Archean, because of the presence in it of undoubted clastics the series is referred to the Algonkian. The same reference is made for the semicrystalline rocks.

[1] Corundum deposits of Georgia, Chap. iv, Geology of the Crystalline Belt, by FRANCIS P. KING: Bull. Geol. Surv. of Georgia, No. 2, 1894, pp. 58–72.

The history, varieties, and characters of corundum, and its mode of occurrence in the holocrystalline rocks, are fully described.

Smith[1] gives a general account of the character, distribution, and structure of the crystalline rocks of Alabama. The rocks are altered sedimentary and igneous rocks. The altered sedimentary rocks, called the Talledega or Ocoee series, is referred to the Algonkian, and the altered igneous rocks are referred to the Archean.

The Talledega series is found in the northeastern part of the state, in four or five roughly parallel belts, running northeast and southwest, the strata in general dipping to the southeast. The series comprises, in order of abundance, clay-slates or argillites, in places impregnated with graphite, quartzites and quartzite conglomerates, and crystalline limestones or dolomites. The slates, quartzites, and conglomerates resemble very strongly certain strata of undoubted Cambrian age, and it is probable that some of the strata included with the Talledega are altered Cambrian rocks. As yet, however, no fossils have been discovered in them.

The altered igneous rocks occur in three main belts roughly parallel with the sedimentary belts in the northeastern part of the state. In order of abundance they are gneisses and mica-schists, cut by dikes of granite, diorite, and various hornblendic, pyroxenic, and chrysolitic rocks.

Gold ores are associated with both the sedimentary and igneous series. Their mode of occurrence is briefly sketched.

Brooks,[2] in petrographical notes on some metamorphic rocks from Alabama, makes general statements concerning the geology of the metamorphic rocks of Alabama and Georgia. The metamorphic rocks of Alabama and Georgia may be differentiated into two series. The older, or crystalline series, includes crystalline schists and gneisses, whose origin is doubtful, together with large masses of gneissoid granite. The younger, or clastic series, is typically made up of phyllites, sericite-schists, chlorite-schists, conglomerates, quartzites, crystal-

[1] A general account of the character, distribution, and structure of the crystalline rocks of Alabama, and of the mode of occurrence of the gold ores, by E. A. SMITH: Bull. Geol. Surv. of Alabama, No. 5, 1896, pp. 108–130.

[2] Preliminary petrographic notes on some metamorphic rocks from Eastern Alabama, by A. H. BROOKS: Bull. Geol. Surv. of Alabama, No. 5, 1896, pp. 177–197,

line sandstones, and in a portion of the region limestones and marbles. The rocks of both series are closely associated with rocks of undoubted igneous origin.

Clements[1] gives notes on the microscopical character of certain rocks from the crystalline area of northeastern Alabama. The rocks include sedimentary and igneous rocks, and others whose origin is unknown. The sedimentary rocks are comparatively unimportant. Disregarding the sedimentary rocks, the rocks as a whole have the characters of Archean rocks.

Hawes[2] gives notes on the microscopical characters of the Alabama crystalline or metamorphic rocks.

Darton,[3] in connection with a discussion of artesian well prospects in the Atlantic Coastal Plain region, briefly describes the occurrence of the crystalline rocks. The crystalline rocks, predominantly granite and gneiss, outcrop along a line which passes from New York City through Philadelphia, Baltimore, Richmond, Weldon, and Columbia, to Augusta, Ga., and thence through Georgia and Alabama. Westward they extend up the gentle slope of the Piedmont Plateau to the base of the Appalachians. To the east they dip below unconsolidated sedimentaries, and along the ocean shore, from New Jersey south, they are 2000 feet below the surface.

GENERAL COMMENTS.

As yet the broader structural problems of the crystalline and semicrystalline rocks of the Appalachian region and the Piedmont Plateau are far from completely solved. It is certain that some of the semicrystalline rocks which in former years have been called Algonkian or Archean are Paleozoic. It seems equally certain that in the Appalachian and Piedmont Plateau region are greatly metamorphosed sedi-

[1] Notes on the microscopical character of certain rocks from Northeast Alabama, by J. MORGAN CLEMENTS: Bull. Geol. Surv. of Alabama, No. 5, 1896, pp. 133–176.

[2] Notes on the microscopic characters of the Alabama crystalline or metamorphic rocks, by G. W. HAWES: Bull. Geol. Surv. of Alabama, No. 5, 1896, pp. 131–132.

[3] Artesian well prospects in the Atlantic Coastal Plain region, by N. H. DARTON: Bull. U. S. Geol. Surv., No. 138, 1896, pp. 18–19.

mentary rocks, many of them being completely crystalline schists and gneisses, which are of pre-Paleozoic age. Further, in this region is a great series of sedimentary rocks known as the Ocoee series, the position of which is not determined, but which may include both Paleozoic and pre-Paleozoic rocks. Apparently all of the series of sedimentary rocks thus far mentioned rest unconformably upon a still older granite-gneiss-schist complex. It therefore appears clear that there are at least three series of rocks represented in the Appalachian region and the Piedmont Plateau, and there may be more.

Until the great structural problems of the Appalachian and Piedmont Plateau region are settled, the only safe course is to call pre-Paleozoic the rocks which are certainly below the Paleozoic, leaving open the question of their further classification as Archean or Algonkian. In the case of the Ocoee, at the present time, the series cannot be placed even as closely as pre-Paleozoic. In work in Maryland, North Carolina, Tennessee, Alabama, and Georgia, as shown by the above summaries, this plan in some cases has not been followed, but rocks supposed to be of pre-Paleozoic age have been somewhat arbitrarily assigned to the Archean or Algonkian. The use of these names, without definite knowledge of the structural features as a basis for the reference, is a hindrance rather than a help to further classificatory work. When the age of a series in the region is more definitely determined, the rocks can be placed as Algonkian or Archean without contradicting previous statements. C. K. LEITH.

REVIEWS.

United States Geologic Atlas, Folio 42, Bidwell Bar, California. 1898.

This folio consists of six pages of text, signed by H. W. Turner, geologist, a topographic map of the district, a map showing the areal geology, and a map showing the economic features, with one page of special illustrations. The quadrangle represented in this folio lies between the parallels 39° 30′ and 40° north latitude and 121° 30′ and 121° west longitude. It comprises a portion of the northern Sierra Nevada and lies chiefly in Plumas and Butte counties. Except a small area in the southwest corner, the quadrangle is drained entirely by the Feather River. As in the other Gold Belt folios, the formations are divided into two main groups: The Bed Rock series, and the Superjacent series.

Bed Rock series.— In this quadrangle the Bed Rock series is comprised very largly of old igneous rocks with minor amounts of Palæozoic sediments. In the northeast corner a single belt of slates, known to be of Juratrias age, is noted. The age of the Palæozoic rocks is known to be in part Carboniferous. In the Diadem lode there occur silicified tests of foraminifera, *Loftusia columbiana* Dawson, this being the first time this fossil has been found in California. Its age is Carboniferous. Other Carboniferous fossils were found at other points in the Calaveras formation. The igneous rocks belonging to the Bed Rock series may be grouped under three main headings:

1. Amphibolite and amphibolite schists, diorite and porphyrite. In all of the rocks of this series, excepting some of the porphyrite, there is a large amount of green aluminous amphibole. The main mass of the rocks of this group are metamorphic lavas and tuffs.

2. Magnesian rocks, comprising serpentine, talc, chlorite and colorless amphibole rocks, all of which appear to be merely different alteration products of rocks of the peridotite and pyroxenite family. The serpentine has resulted from the alteration of facies of the magma rich in olivine and rhombic pyroxene, and the talc, chlorite and colorless amphibole schists from other facies rich in aluminous pyroxene. The

colorless amphibole comprises probably both edenite and gedrite. The magnesian rocks above described are cut by soda-feldspar dikes, which appear to have a genetic connection with the peridotite-pyroxenite magma.

3. Granular intrusive rocks, mostly acid in character, including granite, granodiorite, quartz-diorite and gabbro. All of the granitic rocks are cut by dikes of aplite, which is regarded as the residual acid material of the magma squeezed up into cracks after the consolidation of the granitic rock; and by dikes of a fine grained diorite, which usually contains idiomorphic needles of brown amphibole. The occurrence of these fine grained diorites or diorite porphyries in small dikes at widely separated intervals in the Sierra Nevada, suggests that they are the differentiation product of some other magma. These dike rocks are very similar in mineral and chemical composition at widely separated localities, and appear to be among the latest of the pre-Cretaceous intrusives, inasmuch as the dikes cut nearly all the pre-Cretaceous rocks. It does not seem possible to ascribe the origin of these dikes to a batholithic magma, underlying the range, inasmuch as the rock occurs almost nowhere in masses sufficiently large to be represented as areas on the geological maps. A genetic connection with the great granodiorite batholith underlying the Sierra Nevada, is suggested by the field relations of this diorite-porphyry.

Superjacent series.— The rocks of the Superjacent series in the Bidwell Bar quadrangle consist almost entirely of gravels and Tertiary lavas, and tuffs. During the Neocene period the Bidwell Bar quadrangle was a country of low relief, as were other portions of the Gold Belt. The Auriferous river gravels formation represents deposits made by the rivers of the Neocene period. These are very largely covered at the present time by lavas. While volcanic rocks are very abundant, there appears to have been few volcanoes in the district. The lavas come chiefly from vents located in the Downieville quadrangle, which lies just east. This is not true, however, of the lavas of the plateau west of the north fork of the Feather. These originated in the Lassen Peak volcanic area.

West of Franklin Hill is the base of a former volcano. The Superjacent volcanic rocks are grouped under the following heads:

Basalt:

Older basalt, with litle olivine.

Later basalt, dark colored and rich in olivine.

Andesite :

Hornblende-andesite, tuff or breccia.

Fine grained hypersthene-andesite.

South of Campbell Peak in the canyon of Fall River, is a dike-like mass of fragmental andesite. This is exposed in the bed of the river, and it extends vertically up the sides of the canyon. In the dike material are embedded the fragments of fossil wood (sequoia) It is clear that this dike represents a fissure opened by an earthquake (?) and filled in by the fragmental andesite from above.

Meadow Valley in the northeast corner represents a depressed area, the result of faulting in early Pleistocene time. During a portion of the Pleistocene, this valley was occupied by a lake.

On the northeast slope of Spanish Peak ridge are fine moraines, and evidences of glacial action were found also at many other points. The lowest elevation which sheltered on its north slope a glacier during the glacial period, is the ridge southwest of Buck's Valley. At one point what appeared to be a morainal pond had been formed by a small glacier. The top of the ridge south of this pond has an elevation of only 5800 feet. As a general rule it may be said that in the Sierra Nevada, all those slopes which now shelter snow banks during the entire season, nourished glaciers during the glacial period.

Structure.— A figure is introduced into the text, showing the general parallelism of the schistosity to the granitic masses, which represent intrusions into the schistose rocks. It will be noted, however, that narrow tongues of the granitic rocks at some points cut directly across the schistosity, and it appears probable that the schistosity in the main was developed at a period antecedent to the granitic intrusions and that the parallelism of the lines of schistosity to the contact of the entering granite, is due to these masses being forced aside by the intrusive rock, the separation of the schistose masses taking place most readily parallel to the schistosity. There is evidence of faulting on an extensive scale in the northeast portion of the quadrangle to the east of Spanish Peak, and faulting was noted at the head of Dogwood Creek. A photograph of this fault scarp is reproduced on the illustrations sheet.

Economic geology.— The economic features of the district include a description of the gold vein deposits, and of manganese, iron, chromite and lime and marble deposits. While quartz is the ordinary vein material of the gold deposits, one instance of an auriferous barite vein is noted.

North Carolina Geological Survey. J. A. HOLMES, State Geologist, Bull. 13; Clay Deposits and Clay Industry in North Carolina, by HEINRICH REIS.

There are few things more noticeable and at the same time more gratifying in the recent work of the state geological surveys than the increased attention paid to the economic and industrial portion of the work. So long as it remains necessary to justify the existence of surveys to appropriation committees, it will remain pleasant to point to practical work and direct economic returns in neighboring states. It has been abundantly shown that legislators do not usually object to paying for a reasonable amount of purely scientific investigation, provided only that the practical work waiting to be done be not slighted. It is equally well demonstrated that it is only by conducting work along lines of both pure and applied science that state surveys attain their highest usefulness. They do better work and gain more quickly and hold more securely the confidence of those who pay for this work. Neglect of these truisms has led to the premature cutting off of more than one survey. It is pleasant, accordingly, to note that the reports coming from North Carolina are not only scientific in their accuracy, but practical in their scope. Such a paper as the one under review, by stimulating the development, and, in a sense, advertising the clay resources of the state, must inevitably be followed by direct material benefits. The care taken by the author to suggest changes and improvements in present treatment as well as to note lines of expansion, in view of his wide experience with clays, are exceedingly valuable.

The paper opens with a brief statement of the origin of clays, and a classification of those developed in North Carolina. This is followed by a clear, though condensed, discussion of the chemical and physical properties of clays and of the geography and geology of the North Carolina deposits. The kaolin or china clays, pottery clays, fire clays, pipe clays, and brick clays are then discussed briefly with reference to distribution, character and proper treatment. A large number of analyses and tests have been made, and are not only inserted, but are interpreted. To persons outside the state the chapter devoted to the kaolins will naturally attract the most attention, since it is kaolin from North Carolina which figures so largely in the pottery industry of the whole country. Judging from certain facts brought out in the report the time may come when the kaolin will be extensively used in its

home state. There will, however, be many matters to consider before the attempt is made. The present, being a preliminary report, leaves this as well as many interesting problems of cost, production, markets, and treatment almost untouched. We would like, for example, to know more about the fuel and labor costs, the type of dry houses and speed of drying found best adapted to the various clays, methods of burning, length of water-soaking, and many other things. These will, of course, be discussed in the final report, which will be eagerly anticipated by all interested in the clay industry.

Among the most valuable things in the present paper are the rational analyses and the large number of physical tests. The latter include the determination of the percentage of water necessary to give a workable paste, the approximate plasticity, the speed of slaking, texture, percentage of air and fire shrinkage, average and maximum tensile strength per square inch, the point of vitrification, vitrification and viscosity temperatures, total fluxes, color when burned, and specific gravity. There is nothing new or especially accurate with regard to the plasticity determinations, such general expressions as "lean," "fair," "good," etc., being used. It is not stated how many tests were used in getting the average tensile strength, nor is the range of variation given. In view of the method adopted, a minor variation from the standard cement test, the omission is important. For example, the pottery clay (No. 50) from Blackburn in Catawba county, gave an average tensile strength of 148 pounds, with a maximum of 200 pounds per square inch. Assuming that the minimum varied as much from the average as the maximum, and we have as the result a clay with tensile strength varying from 96 to 200 pounds, over 100 per cent. While some of the figures are closer, this is not exceptional except in the high strength. Other variations are 84 average to 120 maximum, 60 to 81, 14 to 16, 15 to 18, etc. In short, the results, judging from the imperfect data presented, show as wide or wider variation than is common in cements, and there is the same need here for an improved and more accurate test that cement users recognize. It would be interesting to know more also as to the methods adopted in making some of the tests. For example, does the percentage of water necessary to give a workable paste have reference to clays dried to a uniform state or taken from the bank? The difference might be considerable. Was the shrinkage measured in bulk on market products or along single directions on tests bricklets? Without this data the

results are somewhat less valuable for general comparison, though still of great importance. As a whole the report is to be highly commended. It is concise and fresh. It tells not only about North Carolina clays, but incidentally it gives the point of view of the modern student of clays. While no new methods are developed, there are no modern methods of value which have been overlooked. In addition to its other excellent features the paper is well printed and sufficiently illustrated.

H. F. BAIN.

Lehrbuch der praktischen Geologie. Arbeits- und Untersuchungsmethoden auf dem Gebiete der Geologie, Mineralogie, und Paleontologie. Von DR. KONRAD KEILHACK, Kgl. preuss. Landsgeologen in Berlin. 639 pp. Stuttgart, 1896.

The title of this book fairly indicates its scope. It is essentially an exposition of the results to be sought in the field, and in the laboratory study of the materials gathered in the field, and of the methods by which these results are attained. It is the only book with which we are familiar which essays to deal with so comprehensive a subject. Geikie's *Outlines of Field Geology* covers in a briefer way some part of the ground of the present volume. Richtofen's *Führer für Forschungsreisende* gives many suggestions along the same lines. Nevertheless the present volume is so much more comprehensive than anything else which has been written on the subject that it may fairly be said to be without a rival.

Formidable as was the task which the author set for himself in the preparation of this work, it must be said to have been well done. Probably no two geologists would give instructions for the same work in the same way, and no one could be expected to make a treatise on so broad a subject equally satisfactory in all its parts; yet with all the exceptions which might be taken to the order or method of treatment, and with all the shortcomings which specialists in this department or that might point out (and they are neither numerous nor serious), the book might be read with profit by every geologist in the early stages of his work, and many parts of it by men who are no longer novices. The volume is naturally more satisfactory in those departments of geology where study has been longest prosecuted, and where methods and principles have become most firmly established; for example, the

sedimentary fossiliferous rocks. It is less satisfactory (chiefly because of its brevity) in its discussion of the methods applicable to metamorphic rocks, and to formations which are not indurated, and which contain no fossils, such as the drift and the late Tertiary and Pleistocene formations outside the drift-covered areas. Adequate directions for detailed work in these departments of geology would perhaps have carried the author beyond the limits of a volume intended primarily for those who are beginning practical work in geology, and for the intelligent reader who seeks to understand the nature of the work which geologists have to do and the results to which their work leads.

The criticism might be made that at some points the book goes into too great detail. Here and there specifications are given which any student who has had even fairly adequate instruction does not need. If the author intended to make the book so complete that it might be of service even to those who have not had adequate instruction, these details are in place; but for young geologists who have had the teaching which most young men who enter the profession in our country have had, some of the simpler matters might have been omitted.

The volume is so helpful in many ways that teachers of geology would do well to encourage its study by students who expect to make geology a special study. R. D. S.

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GEOLOGY OF A PORTION OF THE SOUTHERN COAST RANGES.[1]

CONTENTS.

INTRODUCTION.

It is the intention to present in the following paper a résumé of the most important results obtained during a detailed study of a portion of the southern Coast Ranges of California.

The area embraces about 570 square miles in the western part of San Luis Obispo county with the town of the same name nearly in the center. It has a length from north to south of thirty-five miles and an extreme width from east to west of

[1] Published by permission of the director of the United States Geological Survey.

twenty-nine miles. The seacoast traverses it diagonally forming the southwest boundary. The region is one of complex structural features and has represented within it nearly all the sedimentary formations characteristic of the Coast Ranges as well as a great variety of igneous rocks. As far as the writer has yet studied the Coast Ranges no other region of equal area has been found to contain so much of geologic interest.

More than six months of the past year has been devoted to field work[1] in this region besides several reconnoissances in former years. It is expected that a part of the results will appear in the form of a folio of the United States Geological Survey, and a complete report later in one of the Annuals.

TOPOGRAPHIC FEATURES.

The main topographic features have a northwesterly and southeasterly direction. The Santa Lucia is the highest and most important mountain range, extending parallel with the coast across the center of the area surveyed. On the south forming the high ridge terminating on the ocean in Point Buchon is the San Luis range. Crossing the northeast corner of the area is the northern extension of the San Jose range. All three ranges are traversed by narrow canyons which open upon broad and almost level or undulating valleys which extend in a northwest and southeast direction between these three important mountain blocks. The area is thus divided into two portions with sharply contrasted cycles of development, that is, recent mountain ranges with steep slopes and traversed by narrow canyons, and broad valleys in an advanced stage of base-leveling.

The Santa Lucia range forms the divide between those streams which flow directly into the Pacific Ocean and those which drain into the Salinas River. The valley of the upper portion of this river crosses the region surveyed between the

[1] The writer was aided in the field by Mr. F. E. Harvey, a senior student in Stanford University, and Mr. Robert Moran of San Luis Obispo, both enthusiastic students.

Santa Lucia and San Jose ranges. South of the Santa Lucia, between it and the San Luis range, are the broad and fertile San Luis and Los Osos valleys opening northwestward to Morro Bay. A series of sharp peaks extends from a point a little south of the town of San Luis Obispo northwest to Morro Rock separating these valleys from the foothills of the Santa Lucia range.

The Santa Lucia range as far as its recent movements are concerned forms a geological unit, and viewed from the south it presents a bold and comparatively regular front and even sky line. The highest portion has an elevation of nearly 3000 feet, and the summit a width of two to four miles. The topography of this range while presenting certain common features yet varies greatly in different portions, owing to the marked variation in resistency offered to erosion by the different geological formations. The Monteveys hales, which are mostly confined to that portion east of Cuesta Pass, are cut by deep V-shaped canyons while northwest of this pass the soft Knoxville shales, extending longitudinally through the centre of the range, exhibit a succession of open valleys.

The granite mountains (San Jose range) in the northeastern corner of the area surveyed reach an elevation of nearly 2000 feet, but do not seem so high because of the elevated valleys about them. They are cut by narrow canyons, but do not rise as abruptly from the adjoining valleys as the Santa Lucia range. This elevation of land is a magnificent example of an ancient base leveled mountain range. Viewed from most any point along the foothills of the Santa Lucia range the numerous furrowed ridges fall into an even sky line many miles long.

The San Luis range attains an elevation of a little over 1800 feet. It consists of a series of sharp ridges traversed by deep narrow canyons. To the east it lessens in height and finally blends with the Santa Lucia range.

The line of buttes extending from the vicinity of San Luis Obispo northwestward and terminating in Morro Rock constitutes the most remarkable scenic feature in the landscape. The buttes

rise from 400 to 1500 feet from open valleys which are but little elevated above tide level, and terminate in Morro Rock which rises out of the ocean to a height of nearly 600 feet. These are undoubtedly peaks of erosion, the hard crystalline rock of which they are composed weathering away much more slowly than the soft strata of the Golden Gate series in which they were intruded.

The extensive valleys south of the Santa Lucia range are underlaid by the oldest sedimentary rocks (Golden Gate series) of the sheet and are, in their general features, of great antiquity compared with the abrupt mountain ranges on either hand. The valley block has acted practically as a unit since the period of disturbance giving rise to the Santa Lucia and Buchon ranges.

The principal hydrographic basin is that of the Salinas. This stream flowing across the northeast corner of the area pursues a comparatively regular course until it empties into Monterey Bay. The remarkable thing, however, about the river is, that instead of flowing in the lowest depression between the Santa Lucia range and the granite mountains, it has cut a channel for a number of miles through the granite flowing in a canyon 500 to 700 feet deep.[1] Its meandering course brings it in places to the edge of the granite, where it receives tributary streams from the Santa Lucia. These transverse streams have so eroded their separating divides in the soft sandstones between the two ranges that they form an almost continuous valley which is strictly a continuation of the valley of the Salinas farther down. This is clearly a case of superimposed drainage, for when the course of the Salinas and its tributaries was originally outlined the present valley region must have been higher than the granite ridge.

A similar superimposed drainage is to be observed in the case of the streams which flow southwesterly from the Santa Lucia range. These traverse the broad open stretches of the San Luis valley, which in its lower portion is not over 200 feet

[1] JOUR. GEOL., Vol. V, p. 576.

above the sea, and separated from Los Osos valley by a divide not 50 feet high, and then pass directly into the San Luis range, cutting across it in narrow canyons at right angles to its course for a distance of over three miles. The most westerly of these streams, the San Luis Creek, has cut through where the range is 1000 feet high ; and the other, Pismo Creek, traverses it where it is but little lower. The watershed between these streams has almost disappeared, and but little change in the topography would cause the whole drainage to pass westward along the northern slope of the San Luis range to Morro Bay. When the courses of these streams were originally outlined the San Luis range probably did not exist, and the general slope of the country was southwesterly. With the beginning of the upward movement along the axis of the range erosion continued to be rapid enough so that the original drainage was maintained.

SEDIMENTARY TERRANES.

An almost continuous series of sediments from the Middle Mesozoic down to the present is represented in different portions of the central and southern Coast Ranges, but owing to the oft repeated mountain-making disturbances the series is not complete at any one spot. Except for the absence of the Horsetown beds, the Eocene, and possibly the marine Pliocene, the series is practically complete in the region under discussion.

In the northern portion of the Santa Lucia range and other portions of the Coast Ranges there is still an older series of sedimentary rocks which are of unknown age, but were involved in the granite magma at the time of its formation and now appear as marbles, schists, etc. All that is known about these rocks is that they are older than the granite, and that the granite itself is much older than the Golden Gate series (Jurassic) which rests upon it with a basal conglomerate. None of these metamorphic rocks appear associated with the granite north of the upper Salinas River, although farther northwest along the same crystalline axis they are extensively developed.

JURASSIC PERIOD.

Golden Gate series. — This series forms the base of the unaltered sedimentary rocks in the central and southern Coast Ranges. The exact position of these rocks in the geologic scale remained a puzzle to geologists for many years, partly because of the scarcity of fossils, and partly because of the obscure stratigraphic relations.

In former papers[1] the writer has advanced considerations for the belief in the pre-Cretaceous age of this series of rocks, and that it underlies the Knoxville unconformably. In later papers[2] the series was named and more definite proofs given of its relation to the Knoxville. During the recent detailed study of the region about San Luis Obispo the question was conclusively settled in favor of the position maintained by the writer. Two lines of evidence aided in the determination. The first concerns the relation of the series to the Knoxville. Both of these groups of rocks are extensively developed in the region in question, each with its characteristic features. The Golden Gate series is most largely exposed along the southern slope of the Santa Lucia range, in the large valleys at its base, and on the northern slope of the San Luis range. A narrow strip also occurs on the northern side of the Santa Lucia range, exposed through faulting. The Knoxville beds begin as scattered outcrops on the southern slope of the Santa Lucia range east of the town of San Luis Obispo and extending northwest through the depression in the range known as Cuesta Pass, expand to form many square miles of mountainous country through the heart of the range. At numerous points on the northern slope of the range, from the Eagle Ranch to the head of Morro Creek, were found patches of the basal Knoxville conglomerate, either resting upon the upturned Golden Gate series, or upturned itself and faulted down into the latter series. Specimens of Aucella were found in strata of sandstone and fine conglomerate within four feet of

[1] Am. Geol., Vol. IX, p. 153; Am. Geol., Vol. XI, p. 70; Bull. Geol. Soc. Am., Vol. VI, p. 71.

[2] Jour. Geol., Vol. III, p. 415; Am. Geol., Vol. XVIII, p. 350.

the base of the beds. Near the road, two miles northeast of San Louis Obispo, the base of the Knoxville beds is exposed on a little hill. It consists of conglomerate, perhaps thirty feet thick, and dips easterly at a low angle. Exposed on either side of the hill and passing through under the conglomerate is one of the pre-Cretaceous basic intrusives similar to others near by in the Golden Gate series. This must have been the old sea bottom on which the conglomerate was deposited. In Reservoir Canyon, a little more than a mile southeast of this locality, is a hill about one-half mile in diameter formed of Knoxville shales and one thin layer of conglomerate. The shales are but little inclined and are underlaid and surrounded on all sides by the upturned and nearly vertical sandstones and associated intrusives of the Golden Gate series. Perfectly preserved specimens of *Aucella* were obtained from a concretionary nodule at the very base of the Knoxville on the south side of the hill.

The second line of evidence, that of palæontology, leads to the conclusion that the series is not older than the Jurassic, the radiolaria as well as the molluscan remains both agreeing upon this point. All the specimens of the latter so far obtained from the series are probably new species and appear to be indeterminate as far as the question of Jurassic or Cretaceous age is concerned. Only one locality of mulluscan fossils was discovered and that is located on the coast, six miles north of Port Harford. A small species of a pecten-like form occurs in great abundance here through a thickness of about eighty feet of black slate which stands vertical and is inclosed between dikes of diabase.

The strata of the Golden Gate series consist of sandstone which forms fully four-fifths of the whole, numerous lenticular beds of radiolarian jasper, shale, and a little conglomerate. The whole has been upturned, folded, and faulted in a very complex manner and intruded at various periods by dikes of igneous rocks in great variety and abundance. The different members of this series have the same character as in other portions of the Coast Ranges where they have been described.[1]

[1] Bull. Geol. Soc. of Am., Vol. VI, p. 82; U. S. Geol. Sur., XVth Annual Report, p. 415.

The sandstone is characteristically thick bedded and in general shows little if any metamorphism, except in the vicinity of eruptive masses. It disintegrates readily, forming a rather heavy soil. It is almost everywhere, however, seamed and fissured, while the softer, shaly strata are often crushed and distorted. The five-mile section along the coast, north of Port Harford, exhibits the relative proportion of sandstone in the series. Along this stretch the strata stand vertical and with the exception of thin layers of shale and several lenticular strata of jasper consists entirely of sandstone. The apparent thickness of this section is fully 10,000 feet, but whether this represents the total thickness of the Golden Gate series is not certain.

The outcrops of jasper are very abundant over the whole of the region occupied by the Golden Gate series, and as they weather away much more slowly than the sandstones form the most prominent of the smaller topographic features, rising often as jagged or rounded knobs above the rolling contour of the hills. There are at least half a dozen important horizons, which, though apparently not confined to any one portion of the series yet are mostly aggregated toward what seems to be the basal portion. The strata of jasper are of very irregular dimensions swelling and pinching and often appearing as isolated lenses, but rarely exceeding 100 feet in thickness. The basic intrusives so numerous in the Golden Gate series occur mostly in that portion occupied by the jasper beds, the latter generally being reddened and often involved in the erupted masses. The contact of the jasper with the sandstone as well as the easy parting of the jasper bands undoubtedly facilitated the passage of the molten matter. The organic nature of the rock is indicated by the minute radiolarian skeletons in which the structure can often be seen with a pocket lense.

Scattered over the area occupied by the Golden Gate series occur prominent outcrops of a metamorphic schistose rock having a predominantly bluish tint. Owing to the general covering of soil the relations of these rocks are not always shown but where exposures are sufficiently good they appear to

be bunch-like or eliptical in form, sometimes 100 feet thick and several hundred feet long, and from this size down to those only a few inches in thickness. Where the inclosing rocks are exposed they invariably lie in contact with one of the fine grained basaltic intrusives. Glaucophane gives the characteristic bluish tint, but other minerals, such as a pearly mica, chlorite, quartz and garnet occur. These rocks possess great interest though the problems connected with their occurrence are not yet all solved. There can be little question that they have been formed through the metamorphosis of argillaceous strata in contact with igneous masses, but why this action was so irregular and intermittant it is difficult to comprehend. It is also puzzling to know why the contact rocks are invariably associated with a certain type of the pre-Cretaceous basic intrusives and not with others, such as the peridotites. The exceeding abundance of the contact rocks through those areas of the Golden Gate series where the old eruptives are the most numerous, indicates plainly that the most if not all the latter are of subsequent origin.

CRETACEOUS PERIOD.

Knoxville Beds.—The rocks of lower Cretaceous age are now confined to the Santa Lucia range, although once probably much more extensive. They form an almost continuous strip from the head of the Corral de Piedra Creek on the south slope of the Santa Lucia range northwest for a distance of over twenty miles. North of Cuesta Pass they widen out forming for a number of miles nearly the whole of the brush-covered mountains between the two crests of the range. The structure of this portion is synclinal and seems to be due to the intrusion of great masses of diabase along its edges and which form the double crests referred to. The beds are perhaps 3000 feet thick and consist of dark shales and thin bedded sandstones closely resembling those of the same age in other parts of the state. Several thin layers of pebbly conglomerate occur, one being at the base and containing numerous pebbles of jasper and other silicious rocks.

The genus *Aucella* is well represented through the lower and middle portion of the shales, but the upper portion appears to be barren of life.

The nonconformity with the underlying Golden Gate series is most marked, not only by the discordance in dip but through much less distortion of the upper beds and the entire absence of the intrusives so characteristic of the lower series. Although so much evidence exists of a break between these two groups of rocks, its real magnitude does not yet seem to be appreciated by geologists as it ought. The more the question is studied the more its importance must appeal to geologists.

Chico formation.—The upper portion of the Shasta group known as the Horsetown beds was not recognized within the area under discussion and it seems probable from the stratigraphic relations existing between the Knoxville beds and the Chico formation that it is absent. The Chico occurs in two widely separated localities. The most important one forms a belt one to two miles wide and many miles long on the northern slope of the Santa Lucia range. The other is a strip about the same width extending along the coast from a point six miles west of Cayucos, northwestward for about eighteen miles. In both areas the rock consists almost wholly of sandstone. Fossils are not abundant but they were found in sufficient numbers in the Santa Lucia Mountains to demonstrate the age of the formation. In the latter locality the sandstone terminates downward in a conglomerate which is in places 100 feet thick, resting either upon the Knoxville shales or the Golden Gate series. The sandstones on the coast rest upon the Golden Gate series exclusively. The relation to the Knoxville shales was carefully examined at many points along the northern slope of the Santa Lucia Mountains and a conclusion reached which is in accord with one already published,[1] namely, that the lower and upper Cretaceous are, in this region at least, separated by a nonconformity. This is shown by the marked discordance in the dip between the two and the extension of the upper across the

[1] JOUR. GEOL., Vol. III, p. 426.

strike of the lower, as well as by the fact that the upper rests indiscriminately upon either the lower Cretaceous or the Golden Gate series. A nonconformity is also indicated by the fact that where the serpentine in this region, as in other portions of the Coast Ranges, comes in contact with the lower Cretaceous, the relation is one of intrusion while the Chico rests upon it undisturbed. The lower Cretaceous was intruded by the peridotite, upturned and eroded before the deposition of the Chico.

TERTIARY PERIOD.

Strata of Middle Tertiary age are widely distributed over this region and probably once covered nearly the whole of it. The Eocene on the contrary is entirely absent although extensively developed to the southeast in Santa Barbara and Ventura counties. It seems probable that during early Tertiary time this portion of the Coast Ranges was above water for if the Eocene ever had existed here it would be reasonable to expect some remnant of it would be met with. The Lower, Middle, and Upper Neocene are all represented.

NEOCENE.

Monterey series (*Lower Neocene*).—With the beginning of the Neocene a subsidance commenced and continued through, or nearly through the Miocene. Finally, almost the whole Coast Range region was submerged and a thickness of rocks in many places of more than 7000 feet was deposited. The most characteristic feature of the series is the bituminous shales. They form its upper portion and reach a thickness of 5000 feet. Below them are limestones, clays, volcanic ash, sandstones and conglomerates. Erosion has removed a large part of these rocks, but the similarity in succession of the characteristic horizons at various points in the area surveyed points to the fact of their former continuity.

The sandstones and conglomerates at the bottom of the series are most prominently developed in the region lying east of the Rinconada Valley, between it and the main granite range.

The thickness of these beds is remarkable, being 6000 to 8000 feet. They occupy the same position with reference to the bituminous shales as similar beds on the upper San Antonio River.

The volcanic ash forms a fairly constant horizon over nearly the whole of the region mapped. Several different centers of volcanic action seem to have existed in this region shortly after the beginning of the Miocene. In the mountains south of San Luis Obispo the ash has a thickness of fully 800 feet, while beginning near the Lion rock at the western end of the San Luis range this bed of volcanic ash extends easterly along the southern slope for a distance of over thirty miles. Near the centers of eruption the fragments are coarse, but farther away the deposit consists of frothy pumice, and in places occurring in beds of glass as fine as dust. On Old creek a small flow of banded rhyolite is associated with the fragmental material. It seems probable from the large amount of ash and small amount of massive lava that the eruptions were of an explosive nature and took place at or beneath the surface of the sea. This is the same eruption as that indicated at Point Sal.[1]

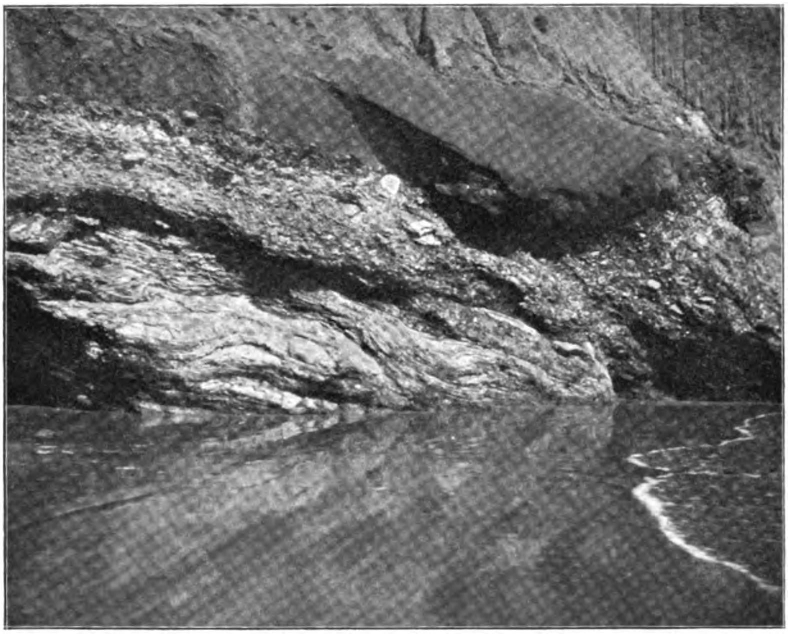
The bituminous shales and flints form the uppermost member of the Monterey series. They constitute the main portion of the San Luis range and that portion of the Santa Lucia range lying east of Cuesta Pass. They also underlie the younger formations in the upper Salinas Valley. This formation measured in both ranges appears to reach the enormous thickness of 5000 feet. It consists almost exclusively of a thin banded silicious shale which over extensive areas has been changed to a flint. Much remains to be done in a detailed study of these shales, although it has been quite certainly proved that they are largely of organic origin.[2] The shales are generally more or less impregnated with bituminous matter, and it appears to be reasonably certain that they constitute the main source of the oil and asphaltum which is so widely distributed through the Coast Ranges. Springs of thick oil and sulphurous water issue from

[1] Bull. Dept. of Geol., University of California, Vol. II, p. 16.

[2] Bull. Dept. of Geol., University of California, Vol. II, p. 13.

them, and when covered by porous beds vast deposits of bitumen have been formed.

San Pablo formation (*Middle Neocene*).—Overlying the Monterey series unconformably is a series of soft sandstones, diato-



Nonconformity between the San Pablo formation and the Monterey series. Ocean cliffs near Pismo.

maceous beds, and some flinty shales. It forms the eastern extension of the San Luis range between San Luis Obispo and the ocean, as well as a considerable area in the upper Salinas Valley. In the latter region it is filled with fossils which indicate the Middle Neocene, but to be more exact, whether the uppermost Miocene or the lowest Pliocene is as yet undetermined. Dr. Merriam has in a recent publication[1] described a series of strata on the southern shore of San Pablo Bay containing a similar fauna which he believes represents a distinct and

[1] Bull. Dept. of Geol., University of California, Vol. II, No. 4.

hitherto unrecognized palæontologic group. These strata it appears overlie those of the Contra Costa county Miocene with indications of a nonconformity, but the fossils collected from them by earlier palæontologists have in some cases been referred to the Miocene, in others to the Pliocene. To this series of rocks Dr. Merriam has given the name San Pablo formation. As the group of rocks in the southern Coast Ranges is undoubtedly the equivalent of those on San Pablo Bay, the latter name will be extended to it. In the San Luis Obispo region the nonconformity of this series of rocks with the Monterey series is distinctly shown in many places. Good examples appear along the coast north of Pismo as well as in the vicinity of Santa Margarita in the upper Salinas Valley. The basal conglomerates of the San Pablo formation, often but little disturbed, lap over on the more highly tilted and disturbed shales and contain many fragments of the latter often filled with mollusk borings. A great interval of time must have separated the deposition of the San Pablo formation from that of the bituminous shales, for the former formation extends over the shales in places and rests directly on the Golden Gate series. This time must have been sufficient for the erosion of at least 5000 feet of the Monterey series. During this time also the chief chemical change was wrought in the bituminous shales, for pebbles of the flinty altered shales occur at the base of the San Pablo formation in exactly the same condition as the shales on which this formation rests.

The discovery by Dr. Merriam of the marked palæontologic differentiation of the fauna of this group of rocks is an important addition to our knowledge of the younger formations of the Coast Ranges. That it is not a local condition is shown by the results reached by the writer along different lines and wholly independently. The pronounced nonconformity so clearly apparent in the San Luis Obispo region is confirmatory of the palæontologic investigations and firmly establishes the validity of the new formation. Its fauna is certainly older than that of the Merced beds, and if it should prove to be the upper-

most Miocene the rocks of that age in California can no longer be looked upon as forming a unit but separated into two divisions by an extended period of elevation and erosion. This point established other and puzzling questions relating to the Miocene and Pliocene are in a fair way to be cleared up.

Paso Robles formation.—The later Neocene in this portion of the Coast Ranges consists of a very extensive series of beds having apparently a fresh-water origin. They fill the Salinas Valley as far up as Atascadero, lapping over unconformably upon the upturned and sharply folded San Pablo formation. They are characteristically exposed about the town of Paso Robles, hence the designation. From Paso Robles the beds extend westward toward the Santa Lucia Mountains, and for many miles north and east of that place, filling the valley of the Estrella and its tributaries, and may reach into the Great Valley. The formation consists of conglomerates, sandy and marly clays, as a general thing, but slightly consolidated. The great extent of this formation in the drainage area of the upper Salinas River, its peculiar character and total absence of marine organisms, or organisms of any kind as far as observed, make it appear probable that it is of fresh-water origin, and for these reasons, though it is possibly contemporanous with the marine formation known as the Merced beds, it should be given a distinct name. The strata are generally almost horizontal, but along the Salinas River in particular they are tilted and faulted. Beds of the same character overlie the San Pablo formation in the vicinity of Arroyo Grande.

Fresh-water beds of Pliocene age are widely distributed through the Coast Ranges.[1] Those in the valleys of the upper San Benito and Salinas have been referred to by Lawson as Pliocene delta deposits,[2] and considered the equivalent of the Merced beds. While the latter view is probably correct, there is no reason to consider them delta deposits; on the contrary, they

[1] Monograph No. XIII, U. S. G. S., p. 238; Bull. Dept. of Geol., Univ. of Cal., Vol. I, p. 152; Bull. Dept. of Geol., Univ. of Cal., Vol. I, p. 363.

[2] Bull. Dept. of Geol., Univ. Cal., Vol. I, p. 153.

have decidedly the character of fresh-water lake beds, and there is no reason to believe that they were ever connected with the Merced beds.

PLEISTOCENE.

Under this designation are included the terrace formations, blown sand, stream gravels, and alluvial bottoms. These were not all formed at once, but represent a complicated history. The terrace formations belong to the oldest division. The most extensive area included under this head embraces a great stretch of sandy mesas and hills between the mouth of the Arroyo-Grande Creek and the Santa Maria River.

The coast, almost everywhere more or less distinctly terraced, forms an elevation of about ten feet above mean tide up to 750 feet. In addition terrace-like effects were noted upon the southern slope of the Santa Lucia range at elevations of 1000, 1400, and 1700 feet, aneroid measurements. In many places along the upper Salinas there are beautiful examples of river terraces cut upon the Paso Robles formation.

IGNEOUS ROCKS.

The igneous rocks of the San Luis Obispo region form one of the most interesting features of that field. Intrusives and surface flows are numerous, especially the former. They are so abundant in the Golden Gate series as in many places to form fully one-third of the surface exposures. The extensive sheets of diabase and peridotite appeared during the Cretaceous, and a great variety, though of much lesser extent, during the Miocene. The age of the andesite and dacite granophyre forming the buttes reaching from San Luis Obispo to Morro Bay cannot be determined with certainty. It certainly antedates the peridotites which appeared at the close of the Knoxville and may be of pre-Cretaceous age.

The igneous rocks, all taken together, show a great range in chemical and mineralogical composition, with examples of rare and interesting types. They have not yet been thoroughly

studied, and no detailed description will be attempted in the present paper.

In the following outline the main types of igneous rocks occurring in this field will be given and arranged in groups according to age:

Granite,	Earlier than the Jurassic.
Basalt, intrusives and surface flows, Peridotite, Diabase,	Earlier than the Cretaceous. Intrusive in Golden Gate series.
Dacite granophyre, Andesite granophyre,	Earlier than the Middle Cretaceous. Possibly pre-Cretaceous. Intrusive in Golden Gate series.
Diabase,	Earlier than the Chico. Intrusive in Knoxville beds.
Peridotite serpentine and related feldspathic rocks, including diabase, gabbro, and pyroxenite,	Earlier than the Chico. Intrusive in the Knoxville and preceding diabase.
Rhyolite, Augite teschenite, and olivine diabase, Quartz basalt, Basalt,	All probably earlier than San Pablo formation. Intrusive in Monterey series.

The granite covers a large extent of country east of the upper Salinas River. It is remarkably uniform, consisting of quartz, biotite, orthoclase, plagioclase, and titantite. Large orthoclase phenocrysts give a porphyritic aspect in places. Numerous dikes of a finer-grained granite intersect it. Nothing is known concerning the age of the granite, save that it forms the southeastern continuation of the crystalline axis of western Monterey county, on which the Golden Gate series rests with a basal conglomerate. It is certainly much older than the Jurassic.

The dikes of basic pre-Cretaceous intrusives in the Golden Gate series are almost innumerable, and, as they are generally much altered, weather away readily and are difficult to map accurately. Owing to the disturbances which the series has undergone, it is also almost impossible to distinguish in all cases the surface basalts from the dikes with similar appearance. The

greater number of the dikes are fine grained and amygdaloidal on the edges. Dikes of diabase are also numerous. The rock having the most limited distribution is the peridotite. This is not as much decomposed as might be expected, considering its

Morro Rock (dacite granophyre) on the coast at mouth of Morro Bay.

age, and consists of olivine, a rhombic pyroxene, and sometimes augite and a little feldspar. The dikes follow the strike of the rocks, and are more abundant in the jasper horizons. Contemporaneous flows were not recognized with certainty, and it is the writer's opinion that they are more rare upon the San Francisco peninsula than Lawson has supposed. They are not all of the same age. The surface flows did not take place until after the Golden Gate series had been upturned and planed off. This is shown in the hills east of Los Osos Valley.

The dacite and andesite granophyres are strikingly interesting rocks. The occur as roundish or lenticular plugs forming the large buttes, besides many small ones, between San Luis Obispo and Morro Bay. The dacite variety is confined to sev-

eral of the northern ones, the andesite to those nearer San Luis Obispo. The important constituents of the former are quartz, biotite, and an acid plagioclase feldspar; of the latter labradorite, biotite, and enstatite, as porphyritic constituents in a granular base. Morro Rock is the most striking topographic feature on the coast of California.

The diabase intrusive in the Knoxville beds has a character different from any other rocks in the region under investigation. It is grayish in color, fine grained, and amygdaloidal upon the edges. It has come up in great dikes or sheets on either side of the main Knoxville area, throwing the latter into a synclinal trough. It extends northwest from Cuesta Pass for many miles, and is quite uniform save for local gabbroitic variations.

The peridotites and related feldspathic rocks of the Coast Ranges are well known. The great body of this rock in the San Luis Obispo region has been changed to serpentine. It consisted originally of olivine and augite. Local variations rich in feldspar occur along the Santa Lucia range forming diabase and gabbro. The feldspathic facies is quite extensively developed not only upon the borders of the great serpentine area north of San Luis Opispo, but also in many places as apparently independent intrusions. From their similarity in character it is easy to see, however, that all these rocks are genetically related. The serpentine has the usual sheet or lense-like character conformable to the dip and strike of the inclosing rocks, which usually stand very steeply.

The igneous rocks of Tertiary age have a great range in chemical and mineralogical composition. The succession of these rocks was only partly determined. The oldest is the rhyolite of which there are two varieties. One contains free quarts and occurs as a very limited surface flow, being mostly represented by tuffs. The other has the form of long, narrow sheets intruded near the base of the Miocene, and contains no free quartz, but an abundance of plagioclase phenocrysts. The ash which is so widespread at this horizon appears to be connected with rhyolite eruptions, but these particular sheets are

probably of later date, as they are clearly not surface flows. The ash reaches in places a thickness of many hundreds of feet, and in the hills south of San Luis Obispo passes downward into an agglomerate of bowlders of perlitic glass, many of them of large size.

The surface flow of rhyolite on Old Creek is very interesting. It is only a few feet in thickness and imbedded in a great mass of tuffs of the same character. The sheet terminates at one edge in flattened nodular masses from one-half inch to eight inches in diameter. Some of these are entirely free, others more or less connected in the plane of flow. Superficially many of these nodules appear like concretions or large spherulites, but their internal character is entirely different. The flowage lines pass through them regularly without regard to the shape of the surface, and the interior appears to have shrunken away from the center, from which radiating cracks either empty or filled with chalcedony spread toward the outside. These cracks break across the banding with but little disturbance of the latter. They do not appear to be real spherulites and the field relations suggest that their peculiar character may be due to sudden cooling under water.

The augite teschenite and olivine diabase form two generally distinct variations of one magma. The former rock contains varying proportions of analcite and its alteration products, augite and a basic feldspar. The typical examples are rather light colored rocks, but with the appearance of olivine and a decrease of feldspar and analcite the rock becomes very dark and basic looking. Some of the olivine diabase contains so little feldspar that it might with almost as much propriety be termed a peridotite. These rocks are among the most interesting of any yet discovered in the Coast Ranges, and as far as is yet known the augite-teschenite is confined to Santa Barbara and San Luis Obispo counties. It has been described in former papers.[1] Not only is it petrographically interesting, but remarkable for its structural relations to the Miocene in which it is intruded.

[1] Bull. Depart. of Geol., Univ. of Cal., Vol. I, p. 273; *ibid.*, Vol. II, p. 19.

The quartz basalt occurs in the form of dikes intruded at the base of the Miocene east of Edna. The larger one is nearly continuous, following the strike of the rocks for two and one-half miles. The rock is dark and fine grained with a few scattering phenocrysts of labradorite feldspar. The most important phenocrysts are quartz scattered in a fairly uniform manner through the rock. The quartz grains show the effects of corrosion and are surrounded by augite microlites. The analysis shows that the rock has a rather low percentage of lime, but there can be no doubt that it belongs among the basalts.

Other Tertiary basalts occur on a small scale at several different points, but they have no striking features and will not be described here. It is impossible to determine the relative ages of these basic igneous rocks, although it would seem that with the exception of the rhyolite they followed the disturbances which folded the Miocene.

STRUCTURAL GEOLOGY.

Nearly all the structural features have a linear arrangement along northwest and southeast lines. The mountains are structurally synclines elevated by comparatively recent movements, the most important being faulting. This region may be divided in a general way into five crustal blocks, as follows, beginning on the north: the granite and associated rocks north of the Salinas Valley, the depression occupied by the Salinas Valley, the Santa Lucia range, the western foothills of this range and the broad valleys at its southern base, and last, the San Luis range. Each of these blocks has behaved as a unit since Miocene, or in several cases very much earlier times. All the faulting now recognizable dates from later Neocene time. The Santa Lucia range constitutes a remarkable fault block. It has been elevated, not by a single fault on each side, but in most places by several forming step faults. A fault line follows the lowest portion of the Salinas Valley, and other lines of folding and faulting are to be seen along the northern slope of the Buchon range.

One of the most striking structural features is the occurrence in the Monterey shales of the Buchon range of great bodies of bituminized sand forced into its present position during the folding which terminated the deposition of the San Pablo formation. There are two of these sand pockets or bosses north of Sycamore Springs. They occur near the ends of subordinate anticlinal folds. The largest body of sand is fully 500 feet across, elongated somewhat in the direction of the strike of the shales and with narrow dikes radiating from it. The sand has probably been forced in from beneath from the adjoining San Pablo formation, as the nose-shaped terminations of the anticlines in which the sand appears have been forced slightly over that formation.

The structural relations of some of the igneous rocks are quite remarkable. Especially is this true of those which have appeared in the Monterey series. Bodies of the teschenite and olivine diabase magmas have come up underneath this series but have rarely if ever broken completely through it. Having penetrated as far upward as the limestones or bituminous shales they have spread out between the strata in sheet form. Two remarkable cases occur north of San Luis Obispo between it and the railroad water tanks. Here are two hills, one a half mile in diameter, the other nearly a mile, rising quite abruptly from the lower rolling country and capped by a thin layer of Monterey limestone and shale. Each hill has an amphitheater-like center, the strata dipping inward from all sides but one, and from this a depression has been eroded. The peculiar topography and saucer-like structure is due in each case to a sheet of teschenite which outcrops around the steep outer slope metamorphosing the overlying rocks. From a general study of the region it seems likely that the Monterey series had already undergone disturbance and folding when these igneous rocks appeared.

One of the crests of the Santa Lucia range about 20 miles north of San Luis Obispo has on its summit a long narrow remnant of Monterey shales folded in synclinal form. For some

miles the center of this syncline has been broken through by bodies of olivine diabase. They appear as dikes or bunches which as exposed in places have lifted up and inclosed large masses of the shale.

On Old Creek there are very large sheets of the diabase, from the upper surface of which the Monterey shales have been nearly removed, as they occur only in patches here and there. These igneous masses in many respects resemble laccolites, only that instead of having arched the strata in dome form they appear as saucer-shaped sheets issuing from lines of fracture along centers of synclines.

GEOLOGICAL HISTORY.

The geological history of this region is exceedingly complicated, and in the short review following only the merest outline can be given. The earliest event of which we have any record in the Coast Ranges was the invasion of the crust by great masses of molten granite, metamorphosing the existing sediments to marbles and schists. The date of this convulsion is unknown save that it must have long antedated the Jurassic. With the beginning of the deposition of the Golden Gate series the great area of crystalline rocks which had for so long a time formed a land mass in the region of the present Coast Ranges began to subside and continued to do so with oscillatory movements until its close. Although this formation is so widespread it is essentially a near shore or shallow water formation as it consists so largely of sandstone. The conditions at times changed and the sea bottom instead of being subjected to sedimentation from the land was covered with the siliceous skeletons of radiolaria which it is believed form the main portion of the lenticular jasper beds.

With the upheaval of the series, and in some cases possibly earlier, appeared dikes and sheets of basic igneous rocks which everywhere so abundantly characterize it. After erosion had planed off the surface flows of basalt took place.

The period of the intrusion of the more acid plugs forming the line of buttes between San Luis Obispo and Morro Bay is

not exactly known. It may have taken place before the deposition of the Knoxville beds.

With the beginning of the Cretaceous the Coast Range region sank and the thin bedded sandstones and dark shales of Knoxville age were formed. They lie unconformably upon the upturned strata of the Golden Gate series and their basic intrusives.

At the close of the Knoxville a disturbance not heretofore recognized in the Coast Ranges took place and the great masses of diabase were formed which threw the beds of that age along the Santa Lucia into a synclinal form. Before the beginning of the Chico another important event took place. This was the welling up of vast bodies of peridotite, now altered to serpentine, which appear everywhere in the Coast Ranges in rocks older than the Chico. Dikes of serpentine penetrate the diabase just referred to and are therefore younger. It is then clear that the conglomerate at the base of the Chico and the nonconformity of this formation upon the Knoxville is due to a widespread disturbance resulting in an elevation of the region above the sea during a portion of the Middle Cretaceous.

The Eocene is absent from this portion of the Coast Ranges and it is legitimate to infer that the region was above water during the whole period.

Before the inauguration of the Neocene sinking commenced, and we find rocks of this period everywhere underlaid by a conglomerate formed as the sea encroached upon the land. Shortly after the beginning of the deposition of the Monterey series violent volcanic disturbances are recorded as having taken place. Local flows of rhyolite occurred and ash of that composition in the form of glass was thrown out in vast quantities and distributed over the sea for many miles. Following this the bituminous shales and limestones were formed. They consist almost wholly of organic material, the more or less blended and broken skeletons of foraminifera, diatoms, and radiolaria. A very extended period of time must have been required for the deposition of 5000 feet of these sediments which are believed to accumulate

slowly. Peculiar conditions must have existed, the sea being practically free from detrital material though the area of deposition could not have been far removed from the land.

The latest igneous action in this region probably followed the initial folding of the Monterey series preceding the deposition of the San Pablo formation, when the basalt, teschenite, and olivine diabase appeared.

After a period of elevation and prolonged erosion during which the great thickness of Monterey series was totally removed from some areas, and the shales of that period had undergone a chemical change, a subsidance began and the sandy strata of the San Pablo formation were laid down. The present configuration did not exist and this formation probably spread across the Santa Lucia range.

The discovery of the nonconformity of the San Pablo formation upon the bituminous shales (Monterey series) necessitates the addition of a correction to the diagram recently published illustrating the oscillations of the Coast Ranges.[1] Two oscillations should appear where the one is represented as separating the Miocene and Pliocene, with the understanding that the dividing line between these two periods is not at present settled.

After a deposition of at least 3000 feet of sediments, elevation and folding were experienced, terminating the San Pablo period; and the outlines of the present mountains were originated.

Marine formations of late Neocene age have not with certainty been recognized in this region. The Paso Robles formation indicates the existence of fresh-water lakes of large extent. With the close of the Neocene an upward movement was inaugurated and continued, it is believed, until the region was much higher than at present.

Following this early Pleistocene elevation a reversal took place and sinking went on until the coast was submerged to the depth of the highest terraces. With the gradual recovery from this depression the lower terraces were formed and again a point

[1] American Geologist, Vol. XX, p. 225.

was reached somewhat above the present. How much this was is not known for the mouths of all streams have been flooded by the ocean. The last movement has been one of subsidance as shown not only by the flooded stream mouths but by Morro Bay, a sheet of water whose origin can only be accounted for by the theory of a depression.

It is hoped that the foregoing discussion will convey some conception of the interesting and complicated problems encountered in the geology of the Coast Ranges.

HAROLD W. FAIRBANKS.

BERKELEY, CALIFORNIA.
June 8, 1898.

THE MIDDLE COAL MEASURES OF THE WESTERN INTERIOR COAL FIELD.

THE most important coal field west of the Mississippi, so far as present development is concerned, is that which stretches from north central Iowa across portions of Missouri, Nebraska, Kansas, Arkansas, Indian Territory, and into Texas. In recent years there has been a good deal of geological work done within this field and some of the older conceptions of its stratigraphy are being changed. It is proposed to discuss here certain problems relating especially to the northern end of the field; that portion extending from central Iowa to southwestern Kansas.

The first extensive investigations of the geology of the Iowa-Missouri coal field were those of Owen[1] who traversed the main streams crossing the region and correctly outlined its limits. He determined the base of the Coal Measures and discovered many important facts with regard to structure and general geology, but made no attempts to build up a general section nor to divide the beds into minor formations. His successors, especially Swallow, Broadhead, and White, applied themselves to this task. Swallow, in an introductory statement regarding the Coal Measures of Missouri,[2] says that they appear to be separated into three divisions by two very important sandstones. These three divisions he calls "Upper," "Middle," and "Lower Coal Series." With the change "series" to "measures" this terminology was generally followed by writers on this region up to 1893 when Keyes, having previously noted the doubtful utility of the term Middle Coal Measures,[3] suggested that the beds were better considered to form two formations which he named the Missouri and the Des Moines.[4] In the succeeding reports of

[1] Geol. Surv. Wisconsin, Iowa, and Minnesota, 1852.

[2] Geol. Surv. Missouri, I and II, p. 78, 1855.

[3] Bull. Geol. Soc. Amer., Vol. II, pp. 277–292, 1891.

[4] Iowa Geol. Surv., Vol. I, p. 85, 1893.

the Iowa and Missouri surveys the beds formerly referred to the Middle Coal Measures have been considered to form a subordinate division of the Des Moines. In Kansas, Haworth has recognized a series of formations of which he correlates the lowermost, the Cherokee shales, with the Des Moines.[1] Above the Cherokee shales and below the Erie limestone, which is at least in a general way equivalent to the Bethany limestone, are placed the Oswego and Pawnee limestones, which with the interbedded shales, would seem to be the equivalents of the Middle Coal Measures of the older classification. Since the earlier work there has been less attempt to build up general sections of the Coal Measures of this field and the tendency has been rather to emphasize the diversity of the beds and the lack of continuity of the strata.

Non-persistence of individual strata is more or less characteristic of all shore formations. It is exceedingly difficult to conceive shore conditions under which beds could be deposited without this being true. When in addition it is remembered that there is excellent evidence that the particular shore line along which the lower Coal Measures of this field were laid down was unstable and subject to change through a considerable vertical range, it will be seen that the attempt to define subordinate formations in the Coal Measures cannot well be expected to yield satisfactory results. All the minor groups which are recognized may be expected to prove of local importance only.

The beds of the upper portion of the Coal Measures, however, beginning with the base of the Missourian formation, indicate that they were found under radically different conditions. Individual bands of limestone, ten feet and less in thickness, may be traced step by step for one hundred or two hundred miles.[2] Bands of black shale, the "slate" of the miners, a foot or less in thickness, seams of impure coal measured in inches only, and thin ledges of impure black limestone of the type elsewhere

[1] Univ. Geol. Surv. Kansas, Vol. I, p. 150, 1896.

[2] Bethany Limestone at Bethany, Mo., H. FOSTER BAIN; Am. Jour. Sci., (4), Vol. V, pp. 433-439, 1898.

least constant in character, maintain themselves over areas of many miles. All of the beds, whether they be limestone made up of beach-rolled fragments, shale suggesting the infra-littoral zone of deposition, or the pure heavy limestone probably marking open sea deposition, are of such uniformity as to force the conclusion that only under conditions of widespread stability could they have been formed. In Kansas and the southern portion of the field there was an important recurrence of shore conditions later in Missourian time. In the portion of the field immediately under discussion, however, this later period of shore conditions is much less important and the uniformity which marks the opening of the Missourian, seems to have persisted throughout the period.

The change from the condition obtaining in the early Des Moines to those present when the Missourian began was a gradual one. During the former period there was no uniformity anywhere, and the field was broken up into a multitude of minor basins of deposition each the theater of an individual sequence of events, while during the latter the whole of southwestern Iowa, northwestern Missouri, eastern Kansas, and probably an even larger area, acted as a unit. The turbulent conditions of the earlier period became merged into the uniform conditions of the later one. Gradually larger and larger areas came to act together and local sequences came to have a wider and wider applicability. It is the beds of this intermediate period which were recognized as the Middle Coal Measures and in the absence of unconformity it will be seen that there is *a priori* reason to expect a series of beds intermediate in character and position between the typical Des Moines and the recognized base of the Missourian. All who have written on the subject have recognized that the Coal Measures mark a continuous sequence of deposition with only local breaks. Any divisions must be more or less arbitrarily established though they may be none the less useful.

The earliest complete section of the Middle Coal Measures published was that of Swallow.[1] A comparison of the plates

[1] Geol. Surv. Missouri, I and II, pp. 82–86, 1855.

given by him with the general section published by White[1] shows a great similarity in the character of the beds, and parts of his section even show a general similarity of sequence. The section given by White was based largely upon investigations carried on along the Raccoon River in central Iowa, a region recently restudied by the present Iowa survey. The section made out in the course of the present work is much the same as a portion of that earlier published. There are, however, certain changes of importance. The upper part as originally published[2] is essentially as given below, the original section numbers being retained.

		Feet
44.	Arenaceous shale and sandstone, - - - -	10
43.	Bituminous shale, - - - - - - - -	4
42.	Lonsdale coal, - - - - - - - - -	2
41.	Shales, light and blue, - - - - - - -	15
40.	Limestone, - - - - - - - - -	5
39.	Shales, light red, blue, arenaceous, - - - -	30
38.	Limestone, impure, dark blue, - - - - -	2
37.	Bituminous shale and coal, - - - - - -	3
36.	Shales, yellow and blue, - - - - - -	5
35.	Sandstone, - - - - - - - - - - -	10
34.	Shales arenaceous, yellow and blue, - - - -	15
33.	Marshall coal, - - - - - - - - -	1½
32.	Shales, blue and yellow, - - - - - -	8
31.	Limestone, impure, fragmentary, bluish buff, -	2

These beds vary more or less in thickness, but maintain the same sequence over a considerable area.[3] The Lonsdale coal is still worked at the type locality and lies about thirty feet below the base of the Bethany limestone. The heavy sandstone, No. 35, is well exposed and easily recognized. Below the section as given there is a sequence composed mainly of shales estimated to be about 150 feet thick. Below this in turn is a series almost identical with that just quoted, but in which

[1] Geol. of Iowa, Vol. I, pp. 272, 1870.

[2] WHITE, loc. cit.

[3] Geol. Guthrie county, Iowa, Geol. Surv., VII, pp. 428–446, 1897; Geol. Madison county, *ibid.*, pp. 504–509; Geol. Dallas county, *ibid.*, VIII, pp. 78–82, 1898.

the coal seams are named Wheeler, Panora, and Lacona respectively. One of the results of the recent work has been to show that this presumed lower sequence is in fact a repetition of the upper portion, brought about by gentle folding.

In following down the South Raccoon River and many of its tributaries the beds already enumerated are easily recognized.[1] A portion of the section is exposed upon Middle Raccoon southwest of Linden, where it is seen to be essentially the same as originally given by St. John.[2] According to the interpretation of that author the beds found in passing both up and down the river from this point were lower. Below the section already quoted he placed a thickness of 145 feet of sandy and variegated shales, and below these a series including three seams of coal and with a sequence remarkably similar to that found above the shales.[3] This hypothesis would require that the beds should rise between Panora and Linden enough not only to compensate for the fall of the stream but to throw high above the river strata deeply buried at the latter point. All dips in the region are slight and the one required here would be greater than any known to be present. Furthermore, recent studies show that the dip from Panora north is in exactly the opposite direction. It seems accordingly that the beds at Panora are to be correlated with the section already given rather than placed below it.

Traveling down the Middle Raccoon the beds rise to Redfield, at which point a thick, massive sandstone fifty feet thick is exposed below them. Below Redfield the sandstone declines and the same sequence as was seen at Linden may be made out.[4] In the southeastern corner of the county the lower portion of the section previously quoted is present overlying a mass of variegated shales. These shales are seen in Polk county, east of Dallas, and only the upper part presents any evidence of regularity. They extend down to the base of the Coal Measures and contain the bulk of the workable coal. The portion

[1] Geol. Guthrie county, pp. 436–437.

[2] See Geology of Guthrie county, p. 430.

[3] See for comparison, Geol. Guthrie county, p. 429.

[4] Geol. Dallas county, pp. 64–67.

which is more or less regular in sequence does not correspond to the lower portion of the Middle Measures as originally described,[1] but shows very different succession.

The Des Moines beds, then, in the central portion of the state consist of a thick mass of shales and sandstones, showing no definite order of arrangement which may be recognized over any considerable area, covered by more regular sequence of which the upper portion may be recognized over a considerable area; but as one travels south two changes take place. (1) The upper member of the section, No. 44, thickness from barely thirty feet on the South Raccoon to over seventy feet on Middle River near Winterset. (2) The various members of the section thin out and are replaced until in the southeastern portion of Madison county none of them can be made out. The section immediately below the Bethany limestone in the latter region is given below. It will be noticed that while none of the beds of the previous section can be recognized, the general character of the strata is the same.

	Feet	Inches
22. Shales, drab, argillaceous, with abundant *Derbya crassa*, *Chonetes*, probably *Chonetes parvus* Shum, at the top,	12	
21. Shales, red, argillaceous, - - - - - - -	3	
20. Limestone, fragmental, earthly, with bits of fossils, -		2
19. Shale, blue to green, argillaceous, grading into red below,	3	
18. Shales, blue to green, sandy, with nodular segregations of limestone, - - - - - - - - - -	12	
17. Shales, blue, calcareous, - - - - - -	12	
16. Limestone, compact, - - - - - - - -		2
15. Limestone, fragmental, loose, with young *Chonetes mesoloba*, - - - - - - - - - - - -		10
14. Limestone, fragmental, but firmly cemented, reddish color, with *Spirifer cameratus* and *Productus costatus*,	1	
13. Shales, green, argillaceous, - - - - - -	29	
12. Limestone, blue to black, in two ledges, with *Spirifer cameratus*, *Rhynchonella* and *Productus*, - -	1	
11. Shale, carbonaceous, - - - - - - -	2	
10. Shale, clayey, drab, - - - - - - - -	1	

[1] Geol. Polk county, Iowa Geol. Surv., Vol. VII, pp. 302–310, and Geol. Iowa (White), Vol. I, pp. 272–283.

	Feet	Inches
9. Shale, yellow, sandy, with marked horizontal bedding planes, - - - - - - - - - - - - - -	4	
8. Shales, black to drab, carbonaceous, - - - -		6
7. Limestone, nodular, sandy, with *Productus cora*, *Chonetes mesoloba* and *Athyris subtilita*, - - - - - - -	1	4
6. Shale, gray, sandy, - - - - - - - -	3	
5. Limestone, similar to number 7, - - - - -		10
4. Shale, clayey, drab to blue, - - - - - - -		10
3. Shale, carbonaceous, - - - - - - - -	1	
2. Limestone, thin bedded, leaf-like in texture, with *Productus muricatus*, *Chonetes mesoloba*, *Derbya crassa* and *Productus costatus*, - - - - - - - - - -		3
1. Clay, green, - - - - - - - - - - - -	3	

South from here in Clark and Lucas counties the work has not yet been carried on in sufficient detail to allow a general section to be made out. It is, however, known that there are in the region strata of the same general type as those found in Madison, Dallas and Guthrie counties, though probably detailed correlation will be impossible.

Along the southern border of the state the Des Moines beds outcrop from the Mississippi River west to Decatur county, where they become buried beneath the Bethany. As far west as the Chariton River the beds may be referred unhesitatingly to the lower division, corresponding, as noted above, with the Cherokee shales. Their character is shown in exposures and mine sections along the Chicago, Milwaukee and St. Paul Railway from Ottumwa southwest.[1] Above these is a formation, including several limestone beds and one widely worked seam of coal, which has been called the Appanoose formation.[2] In general character these strata correspond to those seen farther north at the same horizon. A generalized section is given below:

	Feet	Inches
17. Limestone, gray, subcrystalline, seen in the railway cut near Anchor No. 1 mine at Centerville, and known among the miners as the "floating rock," - - - - -	2–4	
16. Shale, argillaceous, color variable, - - - -	12–30	

[1] Iowa Geol. Surv., Vol. V, Pl. XIV. [2] Iowa Geol. Surv., Vol. V, pp. 378-394.

	Feet	Inches
15. Limestone, heavy ledges, exposed along Manson branch and Cooper Creek at Centerville, as well as at numerous other points in the county, the "fifty-foot limestone,"	4–10	
14. Shale, argillaceous, blue and red in color, - -	14	
13. Shale, arenaceous, frequently forming a well defined sandstone, as in boring No. 3 (No. 13), and the Rock Valley shaft, - - - - - - - - - -	8	
12. Shale, argillaceous, blue to gray, - - - - -	10	
11. Limestone, somewhat variable in thickness; exposed along the C., M. & St. P. railway, between Mystic and Brazil, known as the "seventeen-foot limestone" or "little rock," - - - - - - - - - -	1–3	
10. Shale, sometimes gray, frequently bituminous and pyritiferous, - - - - - - - - - -	7	
9. Limestone, sometimes gray, and coarsely sub-crystalline as at the Lodwick mine, Mystic; sometimes fine-grained, bituminous, and grading into the shales above and below, as at the Thistle mine, Cincinnati; known as the "cap rock," - - - - - - - - - - -	2–4	
8. Shale, usually bituminous, and known as "slate;" occasionally in part soft and clay-like, then known as clod; at times heavy and homogeneous non-fissile, in which form it is known as "black bat," - - - - -	1–3	
7. Coal, upper bench, usually, - - - - - - -	1	8–10
6. Clay parting "mud band," - - - - - - -		2– 3
5. Coal, lower bench, usually, - - - - - - -		8–10
4. Clay parting the "dutchman," - - - - -		½
3. Coal, frequently not so pure, - - - - - - -		2– 3
2. Fire clay, - - - - - - - - - - -	1–6	
1. Limestone, "bottom rock," well exposed along Walnut Creek at Mystic, - - - - - - - - -	3	6

This section was first made out in 1893 and published in the following year.[1] It was not, however, until 1896 that the name Appanoose was applied to the beds. At this time[2] they were defined as a subdivision of the Des Moines formation and sections were given illustrating their relations to the underlying and overlying strata. Above the Appanoose formation there is

[1] Amer. Geol., XIII, 407–411; Proc. Iowa Acad. Sci., Vol. I, Pt. IV, 33–36; Iowa Geol. Surv., II, 407.

[2] Iowa Geol. Surv., V, 378–394.

at one point an unconformable conglomerate.[1] Little is known of this formation, but it seems to be essentially local. The beds between the upper member of the Appanoose, the "floating rock" of the miners and the lowermost member of the Bethany as shown in Decatur county are but infrequently exposed and little is known concerning them. If one may judge from the topography and the infrequent exposures, the intervening beds are shales, predominantly sandy.

The three Iowa sections from the St. Louis limestone to the Bethany may be summarized as below:

Northern Section: Jasper, Polk, Dallas, and Guthrie counties	Feet	Middle Section: Monroe, Lucas, and Clark counties	Feet	Southern Section: Van Buren, Davis, Appanoose, Wayne, and Decatur counties	Feet
3. Sandy shales not to be separated from the underlying formation,	30	3. Beds covered; probably sandy shales,	50–70	3. Sandy shales, only partially exposed, (Chariton Conglomerate, local.)	75
2. Shales, limestone, three coal beds, upper portion of old Middle Coal Measures, -	100	2. Equivalents, section not yet made out,	100	2. Appanoose beds, -	100
1. Shales, heavy sandstone and non-persistent but thicker coal beds, -	400–500	1. Equivalent and similar beds, -	200–400	1. Equivalent and similar beds, -	400-600

The lowermost division is clearly the equivalent of the Cherokee shales of Kansas. The variation in its thickness is due to the erosion unconformity between it and the underlying St. Louis limestone. The middle division exhibits the same general characteristics of thin persistent limestone and coal

[1] Loc. cit., pp. 394–398.

beds throughout the state but varies in detail so much that it is impossible to correlate the individual beds of the north, middle and south sections. The uppermost beds represent a recurrence of the type of sedimentation shown by the lower member and present a notable thickening to the south. Indeed this member is practically absent at the northern end of the area so that the Iowan field includes apparently only the northern half of an immense lense of sandy material, intercalated between the limestones of the Bethany and the Appanoose formations.

As has been pointed out by Keyes[1] there is a close correspondence between the sections made out in Iowa, Missouri, and Kansas. These may be summarized as below.

	Iowa	Missouri	Kansas
3.	No name	Pleasanton	Pleasanton
2.	Appanoose	Henrietta	Pawnee Oswego
1.	Cherokee	Cherokee	Cherokee

The Middle Coal Measures as originally defined included the two upper divisions noted here. Swallow[2] recognized along the Missouri and at the top of his section some thirty feet of sandy shales. White and St. John found about the same thickness along the Raccoon River. Between these two points it is now known that the sandy member attains a considerable thickness and becomes sufficiently distinct to perhaps warrant giving it a separate designation. For this division Haworth's term Pleasanton[3] seems to have precedence if the beds are to be considered as distinct from the next lower formation.

The middle member of the above table includes the major

[1] Proc. Iowa Acad. Sci., Vol. IV, pp. 22–25, 1897.

[2] Op. cit., pp. 82–83.

[3] Kan. Univ. Quart., Vol. II, p. 274, 1895.

portion of the old Middle Coal Measures. As now defined, this median member forms a single well-defined formation, with certain uniform characteristics, and may be well recognized as a distinct unit. Toward the north limestones are thinner and more numerous, while to the south they come together and thicken, until in Kansas they form two well marked beds to which Haworth has given the names Oswego and Pawnee. The Henrietta limestone of Marbut[1] in southwestern Missouri seems to include these two limestones with an intervening shale bed. The whole forms a well defined escarpment which Marbut has traced across the southwestern portion of that state. No detailed section of the Henrietta formation has yet been published, so that the correlation of its individual beds cannot yet be made. In north central Missouri the formation seems to resemble more closely the beds found in southern Iowa, since the Mystic coal is widely recognized in Putnam, Schuyler, and Adair counties.[2] The whole series of sections would seem to indicate a gradual change of character, from the near shore beds of the Raccoon River section to the off shore beds of Kansas. This change is very gradual as the series of sections is taken parallel to the strike.

For this median member of the Des Moines series no good term has yet been proposed. The designations used in Kansas refer to individual parts of the formation. The name Henrietta and Appanose have been applied to distinctive phases of the formation. No general term has yet been used for the Raccoon River beds. If it is thought best to apply to the whole formation one of the names already in use, it would seem that Appanoose would have precedence as being first clearly defined and located. There are, however, objections to this since the Appanoose formation as now defined is coextensive with an important coal bed and hence has a definite economic significance. Henrietta has been used in the general sense here suggested,[3]

[1] Missouri Geol. Surv., Vol. X, p. 44, 1896.

[2] Proc. Iowa Acad. Sci., Vol. I, Pt. IV, p. 36, 1894.

[3] Keyes, Proc. Iowa Acad. Sci., IV, 23; and Eng. Mining Jour., Feb. 26, 1898, p. 254.

but if this usage is to be adopted it would seem desirable that the formation be properly defined and some general section of it, as typically exposed, be given. Since, however, Henrietta was first applied to a distinctive phase of the formation, that displayed in southwestern Missouri, it will probably be found better in the end to adopt a general term for the whole region, retaining the terms now in use, Pawnee, Oswego, Henrietta, Appanoose, and Raccoon River beds, for local use. This is the more advisable, since, while the beds show certain general characters common to all and are probably of essentially contemporaneous origin, they really contain the record of deposition in four and perhaps more essentially distinct minor geological provinces.

H. Foster Bain.
A. G. Leonard.

KETTLES IN GLACIAL LAKE DELTAS.[1]

THE object of this brief paper is to describe a remarkable basin in a glacial-lake delta in western New York, and to discuss similar phenomena in general only so far as to throw light upon this particular case.

Between Canandaigua and Seneca valleys lie three north and south valleys which hold no lakes. The most westerly of these is the Middlesex or West River Valley, which drains south into the head of Canandaigua Lake. The next is the valley of Flint Creek, which flows north. Eastward is another deep valley which drains south into Keuka Lake, at Branchport. Upon the west side of the middle one of these three lakeless valleys, the Flint Creek Valley, lies the little village of Potter. Close behind the village is a conspicuous plateau of stony gravel rising 250 feet above the valley plain. In the middle of this ancient plain occurs the singular basin herein described.

This delta is one of the many phenomena which record the intricate and interesting history of the glacial waters in the "Finger Lake" region. The events leading up to its formation seem to be as follows: During the recession of the front of the ice-sheet there came a time when the southern or upper end of each north-sloping valley was free of ice, and the impounded waters were forced into southward flow.[2]

In the Keuka Valley the glacial waters were at first compelled to overflow directly south into the Cohocton River at Bath, but they soon found a somewhat lower outlet across the eastern rim of the basin through the site of Wayne village and the chain of small lakes. These waters have been named the

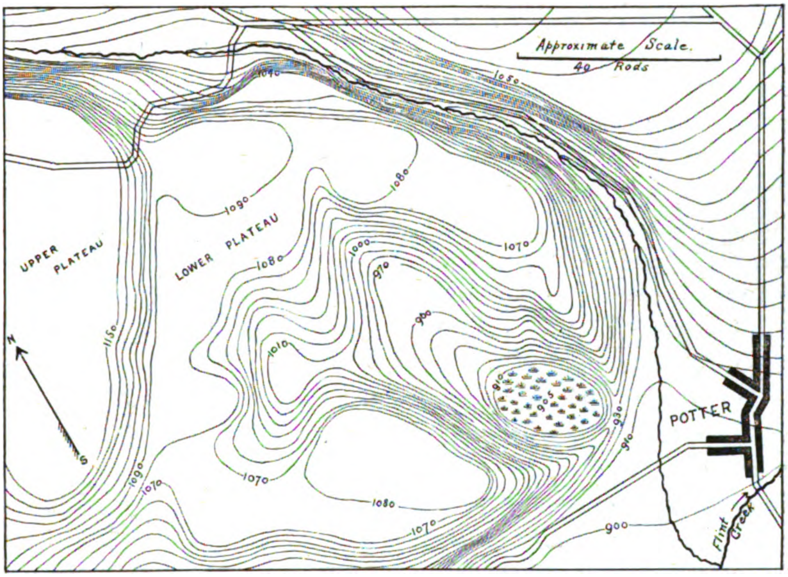
[1] Presented before the American Association for the Advancement of Science, August 25, 1898.

[2] Papers descriptive of the glacial lakes of western-central New York may be found in the Bulletin of the Geological Society of America, Vol. VI, pp. 353–374; Vol. VII, pp. 449–452; Vol. VIII, pp. 269–284.

Hammondsport Lake. Probably somewhat later the southern end of the Canandaigua Valley was occupied by glacial waters, the Naples Lake, which have left a well defined overflow channel near Atlanta. At this level the Naples Lake flooded as much of the Honeoye Valley upon the west, and the West River or Middlesex Valley upon the east, as the recession of the ice-sheet had left open. With further removal of the ice-front a lower outlet for the Naples Lake was uncovered on the eastern border of the Middlesex Valley, about two miles northeast of Middlesex village, and a channel was cut by the escaping waters leading east toward Potter. It was the stream which cut this channel, and drained the waters of the Canandaigua-Middlesex valleys into the Hammondsport Lake, that built the Potter Delta. The ravine is about one mile long. Its depth will average about 100 feet, mostly in shale, with a width at the bottom of about 100 feet, and a uniform gentle grade, with a total fall of about 30 feet. At present it carries no stream. The lower end of this channel is not far above the level of the valley plain of Flint Creek, which indicates that the channel was effective even after the glacial waters in the Flint Creek Valley had found an outlet not far higher than the present plain. Indeed, the gravel and sand plain of the broad valley bottom is probably the filling during the last phase of the glacial waters. The delta represents the earlier deposits at the mouth of the down-cutting stream in the higher or Hammondsport Lake. There are two prominent levels on the delta. Aneroid measurements, using the Lehigh Valley Railroad at Middlesex and Rushville as datum, make the altitude of the valley plain at Potter about 900 feet. The lower and broader delta plateau is about 1080 feet, and the higher, summit plateau about 1150 feet. This higher level corresponds with the summit levels of the several old deltas in the Keuka Valley proper. The lower level represents some stage of the Flint Creek Valley waters not positively correlated at the time of this writing. As the waters fell in the Flint Creek Valley, the ancient stream, continually cutting down to the local base level, bisected and eroded the earlier delta deposits.

While not so extensive as some deposits of similar origin, this delta is a comparatively large one for the ephemeral glacial lakes of the region. By estimate it is about one-third of a mile across.

The form and topography of the delta and the included basin are fairly shown in the accompanying sketch. The dis-



Kettle in Delta at Potter, N. Y.

tances are by eye-estimate and the elevations by aneroid. While the absolute elevations are not exact, the relative heights are approximately accurate. The sketch does not show the rock cut nor the continuation of the two terrace levels along the ravine upon the north side, these being perhaps one-eighth of a mile north of the area shown in the map. The higher level is there a filling of an angle or recess in the hills, about 40 rods wide and with a bar or ridge on the front. The lower level is represented by a rock terrace about 10 rods wide. Behind the higher plateau, on both sides of the ravine, the ground is lower, with ridges and hollows transverse to the stream direction.

The materials composing the delta are quite variable and poorly assorted, containing an unusual amount of large stones and even boulders. This is epecially the case on the northeast side of the 1080 feet plateau, where several heavy stone fences have utilized only a portion of the field stone. These, however, might be wholly attributed to the powerful stream, but many larger and angular boulders on the slopes of the basin are not so explained.

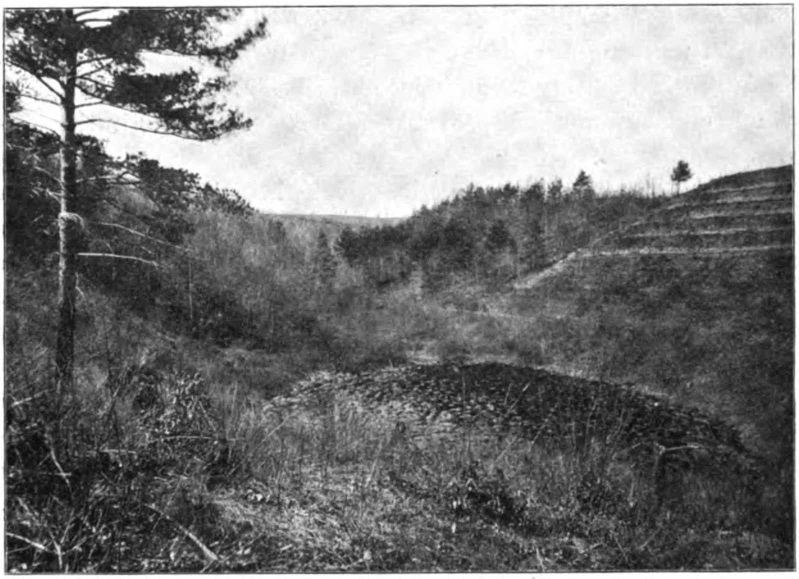
Of the origin of the kettle two hypotheses have been considered; one, that it was a result of capricious currents and deficient filling, the other that the basin is a portion of the space occupied by a block of ice during the deposition of the delta. The first explanation was suggested by the form of the spitlike, sloping ridges on either side of the swamp, the location of the deepest part of the basin at the extreme edge of the delta, and by the existence, in other deltas, of smaller kettles apparently produced by the aqueous forces alone. This explanation is now thought inadequate for the Potter basin.

During the study of this feature correspondence was held with Professor J. B. Woodworth, from whom valuable suggestions have been received. The sketch and photographs were sent to him, and he thought the Potter phenomena similar to other basins which he had studied in New England, and the genesis of which is confidently referred to ice-blocks. The writer accepts this theory for the origin of the Potter basin.

The deepest part of the basin is an oval swamp which holds water until removed, apparently, by evaporation. This indicates an impervious bottom. The depth of the vegetal accumulation is undetermined, but it seems probable that the original bottom of the kettle must have been in till or on rock, and below the water-laid drift. It seems improbable that such a deep hole, with walls so steep, could have been produced as a constructional feature in open water. If such were the case, the spitlike points inclosing the kettle should consist of the finest material brought down by the dying currents. The material, on the contrary, is not sand or even fine gravel, but stony gravel, and the

material of the low ridge at the notch opening into the basin is more like till than it is like gravel. Water movement probably had some part in the formation of the ridges, the currents sweeping about the half buried ice-block.

If the basin were due to deficient filling obviously the inner slopes should consist of finer material dropped by the weakened



Kettle in Delta at Potter, N. Y. View of deepest part looking north.

currents. Such is not the case. The materials are stony, and even large boulders occur. The writer observed no boulders which might not possibly have been rolled by powerful currents, although the much more reasonable explanation would attribute them to ice transportation. The owner of the larger part of the basin said that blocks of stone exist in the basin "as large as a team could haul."

The existence of elevated portions or isolated areas somewhat above the general plateau level might be regarded as due to erosion of the surrounding area, but seem more reasonably

due to contributory deposition by ice, especially as they are quite stony.

The ice-block was probably not entirely buried but projected above the surface of the delta, otherwise the deep swamp kettle would have been partially filled with the water-laid delta material falling in upon the melting ice. The notch at the edge of the kettle is apparently a constructional form, and there is no evidence of any current of water having flowed through it. It is still a narrow ridge, although somewhat flattened or lowered by use for a roadway leading into the basin. The water from the dissolving ice-block probably filtered out through the surrounding gravel.

A natural objection to the ice-block theory is the existence of such an isolated mass of ice for a great length of time. The relations of the stream and delta with the water bodies require the ice-front to be removed some uncertain distance to the northward. This objection, however, has not been given great weight by the students of similar phenomena.

This basin is by far the largest one that the writer has seen in the lacustrine deposits of western-central New York. However, it is not the only one suggesting ice-block genesis. Other deep steep-sided kettles have been seen in the deltas, especially on the slopes of Seneca and Keuka valleys, which may most reasonably be attributed to such origin. The writer has particularly in mind one a short distance above the Hector station, on the east side of Seneca Lake. This seems to lie above the plane of glacial waters and was apparently formed in the exposed delta.

In many deltas, small basins, or hollows, or bowls, occur which have been attributed to aqueous forces alone. These are usually located behind embankments or bars lying transverse to the stream, and vary in form from hollows open at one end to well enclosed kettles. So far as noted, although close study has not been made, the walls are of clear sand or gravel, the depths not great as compared with the breadth, and the forms are simple curves. Their origin seems explained by conflict of waves and

shore currents with the detritus-bearing stream currents. On the lakeward side they are usually bounded by a spit or bar formed transverse to the stream current. Some of the larger and more irregular depressions are bounded landward by the original surface of the valley border, but such are more likely to be open on the side away from the delta-forming stream.

Kettle in Delta at Potter, N. Y. General view, looking northwest from opposite side of Flint Creek Valley.

Those which are confidently referred to aqueous forces occur below the water plane, or are surely subaqueous.

Professor Chamberlin in discussing "kettles," in 1877, suggested four possible methods of origin: (1) Irregularities of deposition or heaping of the drift; (2) the pushing of one drift ridge unconformably against a preceding one; (3) the incorporation of ice-blocks; and (4) under-drainage. To this enumeration the writer would add a fifth method, (5) circum-deposition, by capricious stream currents in the face of wave action, or deficient filling on delta terraces.

The basins which occur in broad stream deposits, and which have suggested the name "pitted plains" have been confessedly difficult of explanation. The notable ones near New Haven have been thought to be due to deficient filling, or to whirling currents in the river. Professor Woodward informs the writer that he is convinced, from his personal examination, that these are of ice-block genesis. Such basins have not been often observed in New York. The best example that has fallen under the writer's observation lies near the village of Tully, upon the south, in the gravel plain left by the glacial waters. It borders the highway leading from the station and village to the Assembly grounds, and is of irregular shape and large extent. The most reasonable explanation is that it was the site of an isolated mass of ice, but whether buried in the gravel or projecting above is not determined, no study of the basin having been made. The occurrence further south, in the same detrital plain, of numerous lakelets, suggests that there are probably many similar basins in the locality.

SUMMARY.

The basins in deltas seem to be divisible into two classes:

(*a*) Those by ice-block origin, and

(*b*) Those by circumdeposition.

These may be discriminated by the following theoretical characters:

(*a*) Shape usually irregular; relatively deep; walls steep; material of the walls coarse or even till-like, with possible boulders; size, often large; position, often above the water-plane. (These characters would be greatly modified in cases where the ice-block was wholly buried in the drift.)

(*b*) Position always beneath water-plane, and usually behind a bar or embankment; depth relatively small; shape, with smooth curving outlines; material of the walls, well assorted and finer than the adjacent delta mass.

HERMAN L. FAIRCHILD.

A SYSTEMATIC SOURCE OF EVOLUTION OF PROVINCIAL FAUNAS.

THE deformations of the outer portion of the solid part of the earth familiarly known as the "crust" are the result of an intricate combination of adventitious and systematic movements. The latter spring from the predominant action of the great stresses that affect the body of the earth; the former, from intercurrent variations in the expression of these dominant agencies due primarily to the rigidity of the earth, and secondarily to inequalities in its density, to changes in its internal temperature, and perhaps to other conditions. Were the earth a homogeneous liquid, the adventitious features would disappear and all its changes of form would be systematic, or if not absolutely all, at least all which seriously affect its deformation. While the adventitious movements that make for heterogeneity of configuration must be recognized, it is the function of the geologist to discriminate and emphasize the systematic factors and to relegate the adventitious elements to their proper subordination.

It is assumed that the fundamental movements which affect the earth's form are centripetal and that the dominant fact in the bodily history of the earth is the shrinkage of its outer parts, as has been so signally urged by Suess. Its upward movements may be regarded as adventitious, since they are incidents due to the restraint which rigidity puts upon a perfect adjustment to the demands of its contractile forces, or to variations from symmetry of substance or of temperature which only become effective through its rigidity. In a slightly different and broader sense, the continents may be said to be adventitious while the ocean basins may be said to be normal. We must hasten, however, to qualify this idea, for the ocean basins have obviously sunk beyond the normal level which the surface of the earth would assume, did not rigidity deform it. The uniform spher-

oidal surface to which an ideal earth would be adjusted lies about 9000 feet below the ocean surface.[1] The portions of the ocean basin below this normal level represent an excess of shrinkage. The continental masses which stand above this average level represent a deficiency in shrinkage. This average level is the natural datum plane from which the continents may be conceived to rise. The ideal upper surface of a continent may be said to be the sea level, a plane which the upper surface of the continent constantly approaches but never entirely reaches. That portion of it which is exposed above the sea level undergoes constant truncation by air and water. The portion beneath the sea level is being constantly built up by the deposition of land wash about its borders, forming a sea shelf whose summit plane is the sea level.[2] As a result of these activities, continued throughout the ages, the continents have come to be approximate platforms whose theoretical upper horizon is the sea level. To this they are accommodated more or less approximately, but never perfectly. They reach their most complete adjustment after long intervals of relative quiescence, when base-leveling attains its highest degree of perfection. They depart most widely from the theoretical surface at the climax of great periods of crustal readjustment to accumulated internal stresses. Such periods of greatest departure inaugurate periods of maximum activity, both on the part of the leveling forces, whose function it is to reduce the land surface again to the sea level, and on the part of the depositional agencies whose function it is to build up a sea-shelf around the borders of the continent. In other words, agencies for the replanation of the platform are put into maximum activity by the very agency which deformed it. If we conceive the continental platform to be the basal portion of a broad truncated pyramid whose bottom rests upon the ideal average level, 9000 feet below the sea surface, and whose truncated summit is ideally at the sea level, it

[1] GILBERT, Article "Earth," Johnson's Cyclopædia.

[2] See "The Ulterior Basis of Time Divisions and the Classification of Geologic History," JOUR. GEOL., Vol. VI, No. 5, 1898, pp. 449–462.

may be said that the widest departure of the average land surface from this ideal summit level has probably at no time exceeded 25 or 30 per cent. of the whole height of the platform, while at times of greatest approximation to the theoretical summit level through base leveling, its departure has probably not reached 10 per cent. of the whole height of the platform. The conception of a continent, therefore, as a platform maintained against deforming agencies by constant truncation of the protruding portions and by constant upbuilding about its borders is not seriously vitiated by the inequalities which crustal readjustments force upon it from time to time.

The ocean basins, considered as inverted plateaus or anti-plateaus, have no analagous agency for the reduction of their bottoms to an ideal plain, and their inequalities are greater (in their broad features, but not in detailed accentuation), and yet here is a reasonable approximation to a bottom plain, for more than half of the oceanic bottom lies between 12,000 and 18,000 feet below sea level. But the variation of 6000 feet included between these limits would be regarded as very large if it were a land surface.

More or less warping of the surface of the solid part of the earth is doubtless in progress at all times, but there is much concurrent geologic evidence to the effect that the really mportant changes are periodic rather than uniformly progressive. The most important items in this evidence are the great base levels and the great epochs of mountain making, the former pointing to long periods of relative quiescence, the latter to exceptional periods of disturbance. In the larger conceptions of the earth movements, the minor warpings may be ignored, but in the interpretation of the details of the earth's history they play a not unimportant part. The degree of importance of this part is dependent upon the critical relationships which the warping may bear to sea-level relations. The present study is concerned with such relationships in their bearing upon the progress of marine life.

The discussion proceeds upon the following general concep-

tions: (1) The continents are platforms whose summits are accommodated approximately to the sea level by truncation and by concurrent circumjacent filling. (2) The normal and the dominant feature of each readjustment of the outer part of the crust to internal contractional stresses is the sinking of the ocean basins and the enlargement of their capacity. (3) The incidental consequence of the sinking of the oceanic basins is the withdrawal into them of an increased amount of the epicontinental waters and the establishment of a new shore line upon the borders of the continent lying at a lower level than the preceding one. (4) The main readjustments are periodic and are separated by intervening stages of relative quiescence. (5) The continental platforms are subject to warping, partly due to the lateral thrust of segments of the earth as they sink (especially those segments that lie beneath the ocean), partly to internal changes of temperature and the intrusion of liquid matter, and partly to the settling of the continent when, by any of the preceding agencies it has been forced upward beyond the plane of isostatic equilibrium, the settling being accomplished through the slow quasi-fluid creep of the rock under gravitative stress.

As a mode of approach to the critical attitudes of sea and land which favor the evolution of provincial faunas, two more general and systematic attitudes which favor respectively general expansional evolution and general contractional evolution may be considered.[1]

1. *Conditions favorable to general expansional evolution of marine life.*—It is to be understood that only that element of marine life is here considered which has for its habitat the relatively shallow sea water adjacent to the land. Geologically speaking we know very little respecting the true abysmal life of the past, and only such little about the surface pelagic life as became incidentally involved in the terrigenous deposits. In considering the shallow-water life adjacent to the land we are, therefore, considering practically that phase of marine life which alone enters effectively into the geologic record. The conditions

[1] These were discussed on pp. 454–459 of preceding number of this JOURNAL.

favorable to an expansional evolution of this shallow-water marine life are those which ensued upon a protracted period of base leveling.[1] This, by its very terms, implies a protracted period of freedom from great movements on the part of the land or the sea. At the climax of such a period there is normally an extensive transgression of the sea upon the continental platform which assumes two phases: (1) the development of broad sea-shelves by the cutting back landward of the sea cliff and the building out seaward of the submarine sea terrace by means of the land detritus; (2) the creeping of the sea waters far inland upon the lower portions of the continent.

At first thought it may be questioned whether the land will not be *extended* by the addition of detritus to its border, and, still further, whether the transgression of the sea is genetically connected with base leveling and is its normal attendant. That the land is now being extended in certain places by detrital accretions to its borders, as in the case of deltas, is beyond question, but it is equally beyond question that the sea is advancing in other places, and it will probably be apparent, after a careful inspection of the continental coasts, that on the average the sea is advancing rather than retiring. But the present is far removed from a base-level period. The streams carry to the sea much more detritus than they would were the surface closely approaching a base level. The sea also, it is to be admitted, is better able to carry detritus back to deep water under present conditions than it would be if its sea-shelf were greatly extended. Conclusions drawn from present conditions are, therefore, embarrassed to this extent on both sides. The issue is really a contest between the ability of the streams to deliver detritus at the coast line and the ability of the sea to carry it back to deep water. The delivery of the streams is a declining factor which approaches zero as the base level is approached. The carrying ability of the sea is much more

[1] A suitable sinking of the land independent of base leveling may produce similar though not quite identical results, but in so far as this is adventitious it does not fall into the category under discussion here.

nearly constant. It is reduced, indeed, by the growing width of the sea-shelf. But the growth of the sea-shelf on its abysmal border must necessarily be slow because of the great depth to be filled, and hence, unless the shelf grows inland, its extension is relatively slight and the ability of the sea to dispose of the detritus borne into it remains nearly constant. With the inevitable decline in the delivery of land wash, as base level is approached, the disposing power of the sea must gain the ascendancy. It would seem to be almost obvious that if there were no movements of the crust for an indefinite period the ultimate result must be the complete truncation of the land to a level below the effective reach of the waves.

But the case does not rest simply with the results of the contest between the diminishing stream action and the nearly constant wave action. There are two supplementary factors which aid the latter. (1) The deposit of the detritus of the land in the sea raises its level. If the average elevation of the present land be taken at Lapparent's figures, 2120 feet, its truncation and removal to the ocean would lift the sea level 700 feet (making no allowance for the spread of the sea). This would certainly be effective in advancing the sea upon the land. (2) The continents after the relative upthrusts attendant upon crustal readjustment probably stand on the average above the plane of isostatic equilibrium, as indicated in the existing status by pendulum observations. From this they should settle back toward equilibrium by virtue of the quasi-fluency of the rocks. The effects of this might, perhaps, decline as erosion proceeded, but the shifting of the load to the borders of the continent would probably aid in depressing them and facilitating the advance of the sea.

The inland extensions of the sea attendant upon such an advance may be conveniently designated epicontinental seas. The great sea which lies between Europe and Africa is properly termed a mediterranean sea, since it really lies between the continents in a deep basin descending to depths of 6000 feet and more. But the seas here referred to as epicontinental are not

of this kind, but are such as are formed by the creeping out upon the low parts of the land of a film of the sea, as it were. The North and the Baltic seas, the Gulf of St. Lawrence and Hudson's Bay are adventitious examples.

It is obvious that at a stage when the sea-shelves and the epicontinental seas were thus extending themselves the conditions for the expansional evolution of shallow-water marine life were signally favorable. In so far as land detritus is inimical to such life, an additional favoring factor is found in the reduction of the surface relief and the consequent diminution of the land wash. The seas at such stages were being not only extended but progressively clarified. A further incident of such stages is the free intercommunication of the life. All of the great continents are at present connected by submerged portions of their platforms and appear to have been so united from the Cambrian times onward. Europe is connected with Greenland by a shallow tract, embracing Iceland, and Greenland, in turn, with the Arctic islands, and thence with the northeastern part of the American continent, constituting a northwest passage for European shallow-water life. On the other hand, Asia is connected by a tract underlying Behring Sea and Straits, and by a broad belt along the border of the Arctic Ocean of unknown width, constituting a northeastern passage for Eurasian life. At times of base leveling there are broad sea-shelves girdling all of the continents, as well as internal epicontinental seas affording other connections; so that altogether the facilities for the migration and the intercommingling of the faunas are exceptionally propitious.

At the same time, as I have endeavored to show in another article in this number,[1] the atmospheric and climatic conditions are uniform and favorable to the widest distribution of life.

In such a period, therefore, is to be found the climax of conditions favorable to expansional evolution and to the development of a world-wide fauna of a composite and comprehensive

[1] The Effects of Great Limestone-forming Epochs upon the Constitution of the Atmosphere, pp. 609.

type. Such faunas appear to characterize the Middle Silurian, the Middle Ordovician, the Carboniferous, and the Cretaceous periods, and in a less pronounced degree the Devonian, the Jurassic, and the early Tertiary.

(2) *Conditions imposing general restrictional evolution of marine life.*—If at the close of a period of great base leveling attended by expansional evolution of marine life, as just outlined, an epoch of profound readjustment to the earth's accumulated contractional stresses ensues, the great feature of which consists of the sinking of the ocean basins or some large part of them, the effect is to withdraw the waters from the surface of the continental platforms into the basins thus increased in capacity and to establish a new shore line somewhere near the edge of the continental platforms. If the enlargement of the capacities of the ocean basins is pronounced, a new shore line may be established, not upon the upper face of the continental platforms, but upon their abysmal slopes. In this case the shallow-water belt will be narrow and will consist of a rapidly shelving shore tract. It is obvious that the great expansional fauna which has occupied the broad sea-shelves and the extended epicontinental seas of the preceding period will be compelled to follow the retiring sea and crowd itself into this restricted zone on the abysmal slope of the continents. It is further obvious that, in addition to the restricted area into which the fauna is thus forced, the new conditions will be in many respects uncongenial, for the streams will be rejuvenated and the amount of land wash will be greatly increased. Those species whose existence is dependent upon clear seas will be in imminent danger of extinction. Certain species to which these conditions are congenial may on the other hand be favored, but the grand result must necessarily be the destruction of the larger part of the previous expansional fauna and the forced adaptation of the remainder to new, and on the whole sterile and hostile conditions. A stage of general repressional evolution is thereby inaugurated and, in a comparatively short period, it is safe to assume, all or nearly all preceding species will have passed out of existence and new species,

in a much more limited number but better adapted to the new conditions, will have been introduced. Such restrictive conditions appear to have been prevalent in a pronounced degree at the close of the Palæozoic era and less notably at the close of the Ordovician period and at other times. But in neither of these cases were the repressional conditions complete, and it is improbable that the ideal conditions of repression here sketched were ever fully realized.

(3) *Conditions favorable to the evolution of provincial faunas.*—It is obvious that if the sea shore be drawn far down the abysmal slope of the ideal sea-shelf, moderate warpings of the continental platform will have little or no effect upon the conditions of faunal development, for whether the shore stands high or low upon this abysmal face the shallow-water tract will remain a mere ribbon. But if, on the other hand, the sea be withdrawn merely to the angle of the sea-shelf the relations between sea and land will be critical and every warping of the surface platform will be decisive either in emphasizing the restrictional influence or in relieving it. To illustrate by a specific case: suppose the sea level to lie accurately at the angle of the ideal sea-shelf, and that portions of the continental platform are warped upward to the amount of 500 feet, while alternating portions are warped downward to an equal amount. The shore line in the former case will lie along the abysmal face and the shallow-water tract will be narrow. In the latter case the shore line will be thrown out upon the upper surface of the sea-shelf and the shallow-water tract will be relatively wide. If the sea-shelf be ideal its upper surface will have a very gentle slope and the downward warping of 500 feet would carry the shore line well inland and give a notable embayment favorable to the perpetration and development of shallow-water life. Under such conditions of alternate warping up and down the continental platform would be bordered by embayments favorable to life, separated by narrow shore tracts which would be largely prohibitive of free migration of shallow-water life between the embayments. Each embayment will there-

fore develop its fauna in measurable independence. Each embayment will become the generating area of a provincial fauna. If now a period of quiescence ensues and systematic continental evolution proceeds, these embayments will become extended landward and grow into extensive epicontinental gulfs and perhaps at length into broad epicontinental seas, and their faunas will expand accordingly. In the progress of this development they may come into conjunction with each other and a commingling and conflict of faunas ensue, resulting in the evolution of a new assemblage of life of a composite type.

Whether the internal progression reaches this stage or not, the development of the sea-shelves must at length attain a stage such that coastal migration will become free and the faunas of the embayments become commingled by coastwise extension. The ideal result of this line of progression is the evolution at length of a general fauna of the expansional type and the concurrent elimination or fusion of the provincial features, for the line of progress is essentially expansional, and the result is expansional evolution. It differs only from an expansional evolution starting from a general restrictional evolution in the commingling and conflict of well-differentiated faunas resulting from provincial development.

At the close of the Silurian period the sea appears to have been drawn away from the land into the critical attitude here indicated, and the basin of the St. Lawrence Gulf and probably that of Hudson's Bay and perhaps other embayments on the borders of the continent, appear to have furnished refuges for the retiring fauna of the Silurian period, and to have become areas in which the origination of provincial faunas took place. The consecutive series of sediments of the St. Lawrence embayment, though not yet perfectly investigated, give good grounds for the belief that the transition of the Silurian fauna into the Helderberg fauna took place there. After its provincial character had been fully assumed and the re-advance of the sea opened the way into the interior through the Champlain tract, it reinvaded the interior basin and left its record as a distinctive

fauna. It was followed in succession by the invasion of the Oriskany fauna, whose place of origin is less clear, but which followed the Helderberg track; by the Corniferous fauna, apparently from the Hudson's Bay embayment; by the early Hamilton fauna, apparently from some southern embayment; and by the later Hamilton fauna, apparently from the Mackenzie embayment, or beyond, thus giving to the Devonian period a distinctive aspect as a time of successive invasions of provincial faunas generated in embayments about the borders of the continent.[1] Had the waters been withdrawn so far as to have emptied these embayments, as was apparently the case at the close of the Palæozoic era, a general repressional evolution would have taken the place of this pronounced provincial evolution. The determinative element, therefore, seems to have been *the critical attitude of the sea to the land* which gave maximum effect to the inequalities of its border.

It is obvious that any previous warping of the continental platform by which a portion of it is submerged may give rise to an embayment covered by relatively shallow water at times of the ocean's withdrawal, and that this may become a refuge for the retreating faunas, and may break the force of the general repressional evolution which would otherwise ensue. This may take place even when the seas are withdrawn down to a level much below the critical horizon just discussed. Such embayments may be regarded as adventitious, since they are not the product of the systematic actions here discussed. But such adventitious embayments were probably always present at times of great withdrawals of the sea, and so broke the force of repressional evolution. In the withdrawal of the sea at the close of the Palæozoic era, the Mediterranean basin appears to have afforded such a retreat for the hard-pressed Permian life of the western part of the Eurasian continent, and to have become a transitional tract in which originated one of the three or four great provincial faunas that advanced upon the land in the Triassic and Jurassic periods. A similar great embayment appears to have existed in

[1] Drawn mainly from the studies of H. S. Williams and Stuart Weller.

the upper Indus and Ganges basins, involving the site of the present Himalayas, and this appears to have been preëminently a transition tract from the Palæozoic to the Mesozoic eras.[1] The adventitious factor in such cases becomes a saving clause so far as the efficient preservation of remnants of the previous fauna is concerned. But even the adventitious factors receive their importance from their critical relations to the systematic attitudes of land and sea upon which chiefly depend the great lines of progress of marine life.

T. C. CHAMBERLIN.

[1] GRIESBACH, Mem. Geol. Surv. India, Vol. XVIII, pp. 1–232, 1891.

THE INFLUENCE OF GREAT EPOCHS OF LIMESTONE FORMATION UPON THE CONSTITUTION OF THE ATMOSPHERE.

THE virtues of carbon dioxide are in inverse ratio to the sinister reputation which "a little knowledge" and a narrow homocentric point of view have given it. As a constituent of the atmosphere it is as necessary to the maintenance of life as oxygen because it is the food of plants and they in turn are the food of animals. Its peculiar competency to retain the heat of the sun renders it a decisive factor in the maintenance of that measurable constancy and geniality of temperature upon which the existence of life depends. It is a leading agency in the disintegration of crystalline rock and is a necessary factor in other geologic changes. It is an essential link in a chain of vital processes which involve all the constituents of the atmosphere. Inherently it may be no more necessary to these processes, save in its thermal nature, than is oxygen, but being the *minimum* factor in the atmosphere it becomes regulative and decisive, because variations in it affect the whole cycle of processes dependent on it, while similar variations in the major constituents may have no appreciable effect. It is the *least* chemical constituent of a mixture that determines the amount of reaction. A loss of nitrogen or oxygen equal to .0003 of the atmosphere would doubtless be wholly inconsequential, while that amount of loss of carbon dioxide would be fatal to life and to many important geologic processes. Oxygen would doubtless become the critical factor if geologic processes in the aggregate consumed it more rapidly than they do carbonic acid. But the reverse seems to be the case now, and it has quite certainly been the case throughout the determinable portion of geologic history. This becomes equally apparent whether we approach the question in the order of the actual processes or the reverse.

Taking the average constitution of the crystalline rocks as a basis, even a rude inspection shows that the consumption of carbon dioxide involved in their decomposition far surpasses the consumption of oxygen.[1] Or, reversing the mode, an estimate of the amounts of carbon dioxide and of oxygen respectively, which would be freed from the sedimentary deposits of the earth if they were again reduced to the condition of silicates analogous to their primitive state shows a like excess of carbon dioxide. From these considerations, which do not need to be given numerical expression, it will be apparent that carbon dioxide has suffered much more consumption in the progress of the geologic ages than has oxygen. That its consumption has surpassed that of nitrogen is too obvious to require argument.

Whatever the original quantitative relations of the atmospheric constituents, the effect of geologic processes has been their reduction to a quantitative order which is inverse to their functional activity. There is hence a preponderance of the inert and relatively non-participant nitrogen, a medium amount of the more active oxygen, and a minimum amount of the most participant element, carbon dioxide.

Now as the activities of the atmospheric constituents are in many respects connected with each other and mutually dependent, it is obvious that the factor which is at once minimum in quantity and maximum in participation must necessarily be the critical factor of the atmosphere. It is not too much to say that the whole order of vital procedure is hung preëminently upon the function of carbon dioxide as the decisive factor, and it is scarcely too much to say the same of many of the most important of inorganic processes.

The chief reservoir of available carbon dioxide on the sur-

[1] The amount of carbon dioxide which crystalline rocks hold in their microscopic cavities, recently shown by Tilden to be considerable, is only a small fraction of what is required for the carbonation of the rock containing it, on the average. We cannot look to this as a source of enrichment of the atmosphere so far as the superficial rocks which undergo chemical decomposition are concerned, though it may be an important source of enrichment when freed from the deeper rocks by the processes of vulcanism and by other means.

face of the earth is not, however, the atmosphere but the ocean. Reservoir in the ulterior sense is not meant, but in the immediately available sense. I entertain the hypothesis that the interior of the earth is the chief terrestrial reservoir of carbon dioxide in the ulterior sense, and that it is a leading source of secular supply. If Tilden's recent analyses of the carbon dioxide stored in the microscopic pores of rocks, or otherwise occluded within them, be representative of the whole interior of the earth, the total mass of carbon dioxide stored within is something prodigious.[1] To how great an extent this is given forth from age to age and becomes a source of atmospheric supply cannot be determined from present data, but I am fully persuaded that the subject is one of the most vital which now invites investigation. The possible feeding of the atmosphere from cosmic sources also invites definite inquiry. But these are ulterior sources of supply of a secular nature and lie apart from the immediate question here discussed. This incidental mention may serve to definitely set them aside and to forestall misunderstanding.

For the purposes of this paper it is assumed that the constituents of the atmosphere and of the ocean have been essentially the same as at present, and no ulterior source of supply or of loss is taken into account. The endeavor here is merely to trace the effects of a great epoch of limestone formation upon such an atmosphere as we now have, attended by an ocean similar to the present one, and with land relations such as accompany great limestone-forming epochs and their antitheses.

A computation of the approximate amount of available carbon dioxide in the present ocean, based upon the observations of the Challenger Expedition as elaborated by Dittmar, shows a content of about eighteen times that contained in the present atmosphere. This embraces only the carbon dioxide held in the two states familiarly known as "free" and "loose;" that is, (1) carbon dioxide which is simply held in solution, and

[1] On the Gases enclosed in Crystalline Rocks and Minerals. By W. A. Tilden. Chemical News, April 9, 1897.

(2) that which constitutes the second equivalent of the bicarbonates—essentially the bicarbonate of lime. The estimate does not include the carbon dioxide which is united with the basic oxides to form monocarbonates and which may be said to be fixed. To put the matter in another form, only that carbon dioxide enters into the computation which separates from the sea water upon evaporation.

According to the old method of interpreting analyses the carbonate of lime present in sea water should all be bicarbonate. It appears, however, from Dittmar's investigations that the amount of "loose" carbon dioxide in the ocean is only about one-half what would be required if all the carbonate of lime (interpreted under the old system) were bicarbonate. The proportions are about as though the lime existed in the state of a sesquicarbonate—a compound of doubtful existence. Under modern methods of interpretation this lower proportion is theoretically explicable, for each of the basic oxides in the sea water enters transiently into combination with each of the acids, and a larger proportion of monocarbonates is thus consistent with solubility, and, in addition, free ions of both oxides and acids are concurrently present. Under this system of interpretation the proportion of carbon dioxide necessary to maintain the lime in a state of solution is reduced. In accordance with these direct determinations it will be assumed in the discussion that the "loose" equivalent of carbon dioxide is only half the amount necessary to render the carbonate of lime a bicarbonate. It is by no means certain that under the conditions of an atmosphere rich in carbon dioxide the amount would not reach the full second equivalent required by the old chemical philosophy, but the more conservative basis serves equally well the purposes of this discussion.[1]

Data are lacking for more than a very rude approximation to the amount of free carbon dioxide held in simple solution in the ocean, but such data as are available seem to indicate that it

[1] The elaborate investigations of Treadwell and Renter (Zeitsch. Anorg. XVII, p. 170) indicate that the lime is essentially bicarbonate so far as it is carbonate at all.

probably does not exceed two or three times the amount held in the atmosphere. If we assume these figures to be approximately correct there remains, in a semi-fixed or loose condition, carbon dioxide to the amount of fifteen or sixteen times the present normal content of the atmosphere. This large reserve of carbon dioxide is the radical factor in this discussion.

Let a status of land and water and of atmosphere and ocean, such as now exist, be assumed. Since a certain amount of carbon dioxide is associated with the monocarbonate of lime in solution as the second or bicarbonating equivalent, and since the secretion and deposition of the lime takes place as the monocarbonate, the associated carbon dioxide is set free. The deposition of limestone is, therefore, a process of conversion of semi-fixed carbon dioxide into free carbon dioxide. This free carbon dioxide under the law of diffusion distributes itself through the ocean and the atmosphere according to the demands of tensional equilibrium. The ocean and the atmosphere are thereby alike enriched in carbonic acid. If this process were continued without reciprocal action of the opposite kind, the ocean would in time be exhausted of its calcium bicarbonate and the semi-fixed factor would all become free.

But as elsewhere urged[1] the disintegration of crystalline rock through the agency of the atmosphere consumes carbon dioxide in the carbonation of the alkalis and alkaline earths contained in them.[2] In particular, the calcium silicates of the crystalline rocks become calcium bicarbonate and are in part carried in solution down to the ocean. Over against the liberating function of lime-deposition, therefore, there is set this reciprocal process of fixation. Over against the enrichment of the atmosphere in carbon dioxide due to the former there is a depletion due to the latter. Now if these two processes were in perfect balance, a static condition of the atmosphere, so far as these factors are concerned, would be maintained. It is, however,

[1] A Group of Hypotheses Bearing on Climatic Changes, JOUR. GEOL., Vol. V, No. 7, October–November, 1897.

[2] The organic cycle and other processes affect the supply and loss of carbonic acid concurrently, but they are purposely omitted here for simplicity's sake.

beyond reason and beyond geological evidence to suppose that these are habitually in perfect or even in approximate balance, for at certain stages the exposure of the land has been large and its elevation high and the process of rock disintegration and carbonation has been notably favored. Coincident with this the ocean has at such times been extensively withdrawn from the continental platforms and the previous expanse of lime-depositing areas thereby greatly circumscribed. In addition to this, the rejuvenation of the streams has at such times brought into the ocean exceptional amounts of detritus and rendered the coasts uncongenial to many of the limestone-forming organisms. It is probable also that even the pelagic calcareous organisms have been at such times adversely affected directly or indirectly by these conditions. On the other hand there have been times when the sea crept out over great areas of the continental platforms and afforded vast expanses of shallow water congenial to the maintenance of lime-depositing life. There is direct palæontological and physical evidence that such extensive epicontinental seas were spread upon the eastern and western continents at the same time, as for example, in the Ordovician, the Silurian, the Carboniferous, and the Cretaceous periods. Geological evidence compels us likewise to recognize recurrent fluctuations in the prevalence of such limestone deposition, intermittent with the antithetical process of land degradation.

Returning now to our selected case based on the present status of atmosphere, ocean, land, and water, we may safely assume that one or the other of the two alternatives, the fixation of carbon dioxide, or the freeing of carbon dioxide, is at present preponderant. Either the carbonic consumption upon the land is in excess of the carbonic freeing in the ocean, or the reverse is the case; if not so momentarily, at least so habitually.

Let us assume, in accordance with the probable fact, that the disintegration of the silicates is now exhausting the carbonic acid of the atmosphere faster than the deposition of limestone eliminates it, and that, therefore, the calcium bicarbonate in the ocean is increasing. The result of this process if prolonged

without interference would be the exhaustion of the carbonic acid of the atmosphere, and, incidentally, the lowering of the surface temperature through the withdrawal of the heat-conserving influence of the carbon dioxide, the reduction of the moisture of the atmosphere through the decline of the temperature, the checking of the vegetal growth, and if the process were to proceed to its extreme, the destruction of vegetal life, and of animal life as well. There would also be concurrent diminution of the chemical disintegration of the rock because of the lessened supply of the disintegrating agency, carbon dioxide, and because of the reduction of the auxiliary agencies, warmth, moisture and vegetation. Theoretically, rock disaggregation by physical agencies might grow into relative preponderance over chemical disintegration, since it would be aided by the sharp oscillations of temperature which would follow the withdrawal of the equalizing blanket of carbon dioxide and aqueous vapor. In such a case the land detritus from crystalline areas would constitute arkose deposits which stand in genetic contradistinction to the limestones, mudstones, and sandstones, which are the result of chemical disintegration through the preponderant agencies of carbonic acid and water. Whether this is really the explanation of the arkose deposits that occur at certain geological horizons is not here seriously considered. The assumed procedure is simply carried to its logical extreme. Arkose deposits may certainly be made locally under present conditions.

But the process cannot reasonably be supposed, under current conditions, to go to the ultimate extreme of destroying all life and subjecting the nude surface to mechanical disaggregation; for the process is self-checking. With the reduction of the carbon dioxide in the air, the rate of consumption is decreased as just indicated. At the same time the ocean is being enriched by the calcium bicarbonate carried down by the land waters, and the conditions there rendered more favorable for the formation of limestone and, through it, for the freeing of the second equivalent of carbonic acid. Even if the rate of freeing this

carbonic acid were reduced temporarily by the indirect adverse influences springing from the impoverishment of the life on the land, the continued reduction of the rate of consumption of carbonic acid on the land must cause it at length to fall below the freeing action in the sea, and the impoverishment of the atmosphere give place to enrichment which would run its course until the preponderance of action was again reversed.

But another element of vital importance enters the problem, the changing attitude of the land and the sea. Such changes may be systematic or adventitious. If they are adventitious the results are beyond easy discussion, but adventitious changes are believed to be subordinate to the systematic changes, since these latter follow (1) from coördinate movements of the earth's crust; (2) from uncoördinate movements of the crust which the ocean coördinates by its leveling function, and (3) from no movements at all. The last is the simplest and most representative case.

Let there be no essential movement of the crust for a prolonged period. That this has been an actual case repeatedly, the base levels of different periods testify. During such a period the height and the area of the land are both diminished. The rate of disintegration of the rocks is consequently reduced, and, concurrently, the rate of impoverishment of the atmosphere in respect to carbonic acid and of the conveyance of calcium bicarbonate to the ocean[1] is also diminished. At the same time the edge of the sea is advancing upon the borders of the land, partly by erosion, partly by the lifting of the sea level by the reception of sediments, and partly, perhaps, by the quasi-fluent creep of the continent toward isostatic equilibrium.[2] This results in the extension of the sea shelf and possibly in the formation of interior epicontinental seas, as exemplified notably in the central epochs of the Ordovician, Silurian, Devonian, Carboniferous, and Cretaceous periods. This extended sea shelf and these epi-

[1] The Ulterior Basis for the Classification of Geologic Time Divisions. JOUR. GEOL., Vol. VI, No. 5, 1898.

[2] Loc. cit.

continental seas furnish conditions congenial to the chief lime-secreting organisms. Preëminently is this true when approximate base leveling attends the wide transgression of the sea, as it normally does, since the two conditions are cogenetic. At such times the waters are relatively free from land wash, and the extended shelves and the epicontinental seas have their greatest availabilities of depth. These are the conditions theoretically most favorable to limestone formation. These seem to be the conditions that actually prevailed at the epochs of great limestone deposition. At such periods great quantities of carbonic acid previously stored in the calcium bicarbonate of the ocean were set free and the atmosphere enriched in carbon dioxide. It was precisely during such periods of special enrichment that the land was most incompetent to impoverish the atmosphere, because it was then smallest and lowest. During the prevalence of these conditions it seems inevitable that the enrichment of the atmosphere should have become notable. A rude computation may give some impression of the quantitative competency of a great deposition of limestone to set carbonic acid free. The limestones of the mid-Ordovician period may be taken as an example. According to the estimate of Dr. Tillo,[1] 17 per cent. of the land is covered by the Palæozoic series and 80 per cent. by the total sedimentary series. Taking no account of the loss by erosion, nor of the portions concealed by the ocean, and making the very conservative assumption that only one-fourth of the sedimentary area is underlain by this wide-spreading formation, and the further excessively conservative assumption that the Ordovician limestones average only fifty feet exclusive of impurities, and that only a half equivalent of carbon dioxide was freed for every equivalent of calcium carbonate extracted from the sea water, we still find the amount of carbon dioxide set free to be sixty times the present carbon dioxide of the atmosphere. It is obvious that this amount could not be extracted from an ocean like the present one without concurrent supply, for it is about four times as great as the ocean's avail-

[1] BERGHAUS' Physical Atlas. Introduction to Geological Maps.

able content. It seems apparent that a process which sets free carbon dioxide in so large a proportion to the total atmospheric content would be competent to vary that content notably, if, as contended, the process is subject to notable variations, and especially if, as also contended, the reciprocating process of fixation varies coincidentally with it so that the two mutually intensify each other's effects.

Dr. Arrhenius[1] has estimated that the addition of two or three times the present amount of carbonic acid to the atmosphere would give the genial climate in the arctic regions which the Tertiary flora indicates. Even if this estimate should be much too small, it would not seem to be beyond the competency of a great limestone-making epoch to enrich the atmosphere in carbonic acid sufficiently to thermally blanket the earth effectively and to so retain, distribute, and equalize the temperature as to render all latitudes available to vegetal and animal life. The notable feature connected with the extension of life to the high latitudes is the marvelous equalization of temperature. White and Schuchert[2] have recently given great emphasis to this by showing that in the Potomac epoch an almost identical flora flourished in north Greenland and in Virginia. A simple increase of solar heat, distributed as it is today, does not meet the demands of the problem. An equalizing and distributing factor seems to be indicated. And this, eminent physicists from Tyndall to Arrhenius encourage us to believe may be found in a change of the atmospheric constitution in the critical item of carbon dioxide, a change of no excessive amount and without serious variation in other constituents, except as they follow from this incidentally.

If the freeing of carbonic acid incident to limestone deposition were a potential factor in the equalization and amelioration of climate which permitted the extension of warm-temperate life to high latitudes, such extension should be coincident with the great limestone-forming epochs. Such appears to be the

[1] Phil. Mag., S. 5. Vol. XLI, No. 251, April 1896, pp. 237–279.

[2] Bull. Geol. Soc. Am., Vol. IX, pp. 343–368.

testimony of geological history. It was in the Middle Ordovician, the Middle Silurian, the Middle Carboniferous, the Middle Cretaceous and the early Tertiary that life of the warm temperate types prevailed in the arctic lands. And these seem to be periods of base leveling and of wide incursions of lime-depositing seas. It cannot at present be asserted, on the other hand, that there were intervening periods when warm temperate life did not prevail there, and could not because of low temperature. In the very nature of the hypothesis here entertained, such periods would be coincident with relative land elevation, and their record would be absent, or so obscurely indicated that only critical investigation directed to the point could detect it.

But in the lower latitudes we find evidence of aridity and of cold temperatures intervening between at least some of the periods of extensive limestone formation, as, for example, the saline deposits which took place between the great limestone-forming epoch of the mid-Silurian period and the similar epoch of the Devonian; or, again, the saline and gypsum deposits and red sediments of the Permian and Triassic age between the limestone epoch of the Carboniferous and that of the Jurassic. In this gap also falls perhaps the glaciation of India, Australia, and South Africa. The Pleistocene glaciation and the measurable aridity of recent times, falling between the limestone-forming epoch of the early Tertiary and a possible limestone-forming epoch of the future which should theoretically follow upon the degradation of the continents, if crust movements remain in abeyance, may form another example.

In considering the antithetical epochs where limestone formation is at a minimum, and rock disintegration is at a maximum, it may be noted that at the close of the lime-depositing epoch the ocean is low in calcium bicarbonate and rich in carbonic acid, and is not then predisposed to deposit lime chemically, but is, on the other hand, in a condition to receive and hold the calcium bicarbonate sent down from the land. When, therefore, an epoch of special earth shrinkage and of readjustment to accumulated stress ensues, and the ocean is more fully drawn into the

deepened basins and the land exposed and incidentally corrugated, the conditions for the reversal of the atmospheric change are propitious.

If a computation be made of the amount of carbon dioxide that would be required to disintegrate the crystalline rock requisite to supply the clastic material for a great epoch of sandstone and shale deposition (allowing duly for old clastics used over), a competency to exhaust many atmospheric equivalents of carbonic acid will be shown. This, being correlated with limited limestone formation, and consequent scant returns of carbonic acid from the ocean, seems competent on its side to notably change the constitution of the atmosphere in the direction of poverty of carbonic acid.

The effect of the limestone-depositing epochs upon the atmospheric oxygen and nitrogen has been ignored for simplicity. While doubtless important, the process does not seem to have any such potential consequences as those which attend the decisive and regulative factor carbon dioxide. Its discussion will therefore not be undertaken here.

The action of intercurrent agencies has been purposely ignored. Some of these are quite obvious. The organic cycle of carbonic acid consumption and oxygen liberation by plants, and of carbonic acid production and oxygen consumption by animals, and the coördinate fixation and freeing of nitrogen alternately, was an ever present factor, and contributed in its own way to a constitutional change of the atmosphere. Although the cycle is measurably self-supporting, it is not a solution of the problem of perpetual motion, and the total result for a protracted period is a permanent alteration of the ratios and of the absolute amounts of the constituents of the atmosphere. But the discussion of this is reserved.

The periodicity of epochs of great limestone-formation reciprocating with epochs of great land extension has been assumed on the basis of a recent discussion.[1] That there were intervening

[1] The Ulterior Basis of Time Divisions and the Classification of Geological History. This magazine, previous number, pp. 449–462.

epochs when neither the one nor the other were greatly preponderant is not only not questioned, but will, in a separate article, be urged as the special agency of an important function in biological, as well as geological, progress.

Other limitations will suggest themselves, as the change of calcium carbonate into calcium sulphate, and the reverse, in the sea or in the course of organic processes, but it is believed that none of them radically affect the particular function herein assigned to great epochs of limestone formation.

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STUDIES FOR STUDENTS.

THE DEVELOPMENT AND GEOLOGICAL RELATIONS OF THE VERTEBRATES.

III. REPTILIA.—(*Continued.*)

THERIODONTA.—This name is applied to what must be considered as a very unstable order of the reptilia. Composed as it is of the least well understood of the reptilian forms, it may at any time fall asunder under the light of new discoveries and be seen to be composed of several well defined orders instead of being a single one. The animals making up the order were originally placed by Owen in his *Anomodontia*, in the family *Cynodontia*, but were soon taken out and placed in a separate order, the *Theriodonta*. Owen's classification was arranged on the forms from South Africa only, and it was soon found that it would not suit the forms from America and Russia. Many schemes have been proposed to accommodate all of the different groups, but none has been arranged as yet that is at all satisfactory; there seems to be a general recognition of three distinct groups, but the value of these is a matter of much dispute. Lydekker, in his catalogue of the reptiles of the British Museum, would call the *Theriodonta* a suborder of the order *Anomodontia*, while Seeley, of the same institution and on the evidence of the same material, raises many forms that Lydekker regarded as families into separate and distinct orders. A quite common opinion among palæontologists, and one that may be of the greatest service to the student, is to regard the *Theriodonta* as an order and the three separate groups as suborders—the *Pelycosauria*, the *Cynodontia*, and the *Gomphodontia*.

The first of these the *Pelycosauria*, is represented most largely in the Permian deposits of the United States, but a few isolated

specimens have been found in the same horizon in Bohemia. They were in some respects of the most primitive type; the skull retained the two post-orbital arches, the teeth were simple in structure and without tubercles or basal band; the vertebræ were deeply bi-concave and pierced for the passage of the notochord; intercentra were present, and the sacrum was formed of two or three vertebræ. Not only were they the most primitive members of their order, but they were among the earliest of the land-living vertebrates after the *Amphibia*, and it is very interesting to note among their characters certain features that clearly foreshadow the culminating point of the order, the mammalia. Such characters are the great flattening of the quadrate bone and the partial surrounding of this element by the temporal bones of the skull, and the beginning of a differentiation of the teeth into specialized regions.

Dimetrodon, from the Permian of Texas, is the best known member of the suborder. There were two post-temporal arches, and the bones of the temporal region were all separate. The eyes were very large, almost perfectly round, and placed far back in the skull. The skull itself was abruptly terminated behind, and extended forward as a strong and rather high nose. The upper jaw was slightly convex on the alveolar border, and was armed with many strong, conical teeth that curved slightly to the rear; there were about three incisors in the jaw, the posterior or outer one being much larger than the others. Behind these came a considerable interval, marked by a deep notch at the junction of the premaxillaries and the maxillaries. Posterior to this came one or two very large teeth in the position of canines, followed by a long series of small conical, slightly recurved teeth of nearly equal size. The alveolar border of the lower jaw was concave to correspond to the curve of the upper, and there were two or three large teeth corresponding in position to the canines of the upper jaw. The surface of the palate and the pterygoid bones were covered by rows of small teeth. The quadrate was much depressed, and only appeared for a very small space on the side of the skull, being nearly covered by the adjoining bones. The

lower surface of the quadrate shows two parallel notches that accommodated a double condyle on the lower jaw. This absolutely prevented any lateral movement of the jaws in mastication. Not the least peculiar thing about the animal was the enormous extension of the neural processes of the spine; these were long and slender, becoming nearly as thin as a whiplash at the upper extremity. They sometimes reached a length of nearly three feet, as much as twenty-eight times the greatest diameter of the supporting vertebra. The limbs were short and stout, but from the location of the articular surfaces it seems that the legs were permanently bent, and that the animal could not raise itself from the ground. It is probable that it dragged itself along after the manner of the crocodiles. It is difficult to say what the appearance of the animal may have been. It is pretty certain that the immensely tall spines were clothed with at least a thin covering of muscle and skin, and then there would have been simply a tall dorsal fin that extended the whole length of the body. The tail of the animal was long, and the feet were strong and provided with claws. The whole brute could not have been less than eight or nine feet long.

Clepsydrops is a much smaller genus, known from the Permian of eastern Illinois and Texas. In general features it does not differ from *Dimetrodon* as far as the skeleton is known. It did not exceed a length of two or three feet.

Naosaurus can be told from *Dimetrodon* by the fact that the spines are not only elevated far above the bodies of the vertebræ, but are supplied with cross-bars like the spars of a full-rigged ship. The spines are larger and heavier than in either of the preceding genera, and are marked with shallow grooves that indicate the position of blood vessels, showing that they were covered with a layer of muscle of some thickness. Besides its occurrence in the Permian (Wichita division) beds of Texas, this genus is known from the Permian (Gaskohle) of Bohemia. The specimens from the latter locality indicate a smaller form, about two or three feet long, while the Texas specimens belong to animals nearly or quite as large as *Dimetrodon*.

The habits of these animals are a matter of great doubt. That they were very pugnacious, is well shown by the frequent fractures in the long and slender spines, which must have suffered severely when the animal got into a fight. They were carnivorous in diet.

From the Permian rocks of Russia come some very imperfectly known forms that seem to belong to this group. These are the fragmentary remains of animals discovered for the most part in working the copper mines on the west flank of the Ural Mountains in the provinces of Kasan and Orenburg in the old government of Perm. The remains are almost entirely from the upper layers of the Permian. They did not have the greatly elongated dorsal spines of the American and Bohemian forms.

Brithopus. — This form was described by Kutorga as early as 1838 from the province of Kasan, from what he then called the Keupfersandstein, now known to be upper Permian. The specimen consists of an imperfect humerus, showing the characters of the *Pelycosauria* and the African forms.

Rhophalodon is from the same region in Russia. It is characterized by the same features of the limb bones as the former genus, but the skull is unusually short and of great vertical extent; so great, indeed, as to give to it an absurdly square outline from the side view. The teeth are much stronger and stouter than those of the American forms, and have a tendency to develop in the lateral direction, giving them a rather broad outline and an appearance very similar to that of the American *Pareiasauria*, the *Diadectidæ*.

Deuterosaurus, from the province of Orenburg, in the same part of Russia, is even more similar to the American forms than the *Rhophalodon*; the skull is almost identical in appearance with that of the genus *Dimetrodon*. It seems strange at first sight to find these closely related forms from such widely separated regions as the United States, Bohemia, and Russia; but if we reflect for a moment that despite the great specialization of the American forms in the dorsal spines, this group is the most

primitive of the land-living reptiles, we may find a reason for the widespread distribution of the group.

The *Cynodontia.*— Under this head is grouped the majority of the South African forms, all except those that by their skull structure approach very nearly to the *Mammalia.* The forms considered here are the ones placed in the families *Galesauridæ* and the *Tapinocephalidæ* by Lydekker, in the catalogue of the fossil reptiles of the British Museum, under the suborder of *Theriodonta.* The group at first glimpse seems very like the *Pelycosauria*, but there is one very important distinction. The two postorbital arches of the first group have disappeared and are replaced by a single one that is either made up of the union of the two primitive ones, or is the single one left after one of them has disappeared; in all probability the first of these cases is the true one. The teeth are of carnivorous type, recurved, and in many cases differentiated into incisors, canines, and molars.

These forms are exclusively from the Karroo formation of South Africa. The position of this formation is not definitely known. It is either Permian or Permo-Triassic. If the evidence of the vertebrate remains is to be taken, it should be placed as far up in the geological time scale as possible, for there are found in these beds remains that are very closely related to forms that are found in the Lower Cretaceous of the United States.

Galesaurus, known from the skull only, was a small, lizardlike animal; the skull was depressed, with a rather long muzzle and very large temporal vacuities. The teeth were differentiated into the incisors, canines, and cheek teeth. The cheek teeth were furnished with small lateral cusps at the base. The whole skull was nearly four inches long.

Aleurosaurus is also known only from the skull. The muzzle is long but quite high, resembling in this respect the nasal portion of *Dimetrodon.* The teeth are simple and without the lateral cusps. There is a single large tusk in the upper jaw in the position of a canine. The posterior part of the skull is abruptly truncated, as in the previous suborder.

Lycosaurus was a larger form, with a skull nearly eight inches long. The upper jaw was very convex on the alveolar border, and the lower jaw was correspondingly concave. The whole skull was much depressed.

Cynognathus.—This genus is in some respects the most nearly related of the *Cynodontia* to the *Pelycosauria*, and in others most closely to the succeeding group, the *Gomphodontia*. The general aspect of the skull is that of the *Pelycosauria*. The cranial region is abruptly terminated; the jaws are curved on the alveolar border, and the teeth are divided into the separate regions. There is, however, only a single temporal arch that is almost certainly made up of the two primitive arches combined. The teeth are cuspidate, with a single tubercle in front and another behind. These are developed on the sides of the tooth as well as on the front and rear giving the first appearance of the tubercular type of the teeth. The palate bones also present a step in advance of the reptilian form. They are extended and unite in the median line, thus forming a separate cavity for the nasal organs. This, however, does not extend very far back, ending at about the middle portion of the roof of the mouth. The occipital condyle is almost double, the two sides being greatly developed at the expense of the median portion. The whole skull of one of the best known species was about fifteen inches long. The vertebræ, pelvis, and limb bones all show the same characters as the preceding group.

Gomphodontia.—The suborder is thus described by Seeley: "The *Gomphodontia* comprises animals with a Theriodont type of dentition, in which the molar teeth are expanded transversely, and have more or less tuberculate crowns of the type shown in *Diademodon*. The superior and inferior teeth are opposed to each other, and the crowns become worn with use, as in the Ungulate and other Mammals, and as in the Iguanodont reptiles. The canine teeth of the upper jaw appear to be worn at the extremities.

"It (the skull) appears to show mammalian proportions and aspect, in the definition of the large temporal vacuities, by a

zygomatic arch, which is formed by the molar and the squamosal bones, and in the separation of those vacuities from each other by a long, narrow, parietal crest. The orbit of the eye, however, is separated from the zygomatic vacuity by a postfrontal bone, so that the structure is distinct from that which obtains in the 'mammals.'

"There are two well-defined occipital condyles at the back of the base of the skull, united to each other inferiorly in a way that is closely paralleled in some mammals. The hard palate formed by the maxillary and palatine plates terminates transversely in the middle length of the molar teeth in a way that is remarkably like the dental condition of certain Marsupial mammals.

"So far as is known, there is no fundamental difference in the skeleton to separate the *Gomphodontia* from the *Cynodontia*, which may be regarded as related in the same way as are groups of the Marsupials with similarly differing dentition."

The group *Gomphodontia*, as the author of the suborder says, does not obliterate the interval between the mammals and the reptiles, but it does close up the gap to a large extent, and we are well able to see what must have been the few final steps that led to the formation of the *Mammalia*. If the quadrate should entirely disappear and the teeth take on ever so little a difference in form, if the bones of the squamosal region should coalesce, as they have almost done already, there would be no place where we could say this is reptile and this is mammal.

The known genera of this suborder are: *Tritylodon*, *Trirachodon*, *Diademodon*, *Gomphognathus* and *Microgomphodon*.

Tritylodon was originally described as a mammal by Owen. It is known only from the imperfect upper portion of the skull. The skull was long and rather narrow; the anterior nares were joined in one external opening; there were no incisor teeth, but a large pair of canines; the molar teeth were broad and supplied with three rows of tubercles; between the canines and the molars there was a long diastema. The specimen is from the Permian of Basutu-land in South Africa. From the same region

Seeley has described the forearm and forefeet of an animal that he called *Theriodesmus* which may belong to *Tritylodon*.

From the upper Triassic of Wurtemberg, near Hohenheim, Fraas has described a single tooth that bears a very striking resemblance to the molar teeth of *Tritylodon*. This tooth he calls *Triglyphus*.

Diademodon is from the eastern part of the Cape region of South Africa; it is known from an imperfect skull showing the palate and the teeth. The characteristic part of the skeleton is the broadly tubercular teeth; they are flat or cupped on the grinding face, with the edges showing many small tubercles; the appearance is not unlike that of the pig or the human tooth.

In other characters than the teeth the genus is very similar to the *Cynodontia*, and the chief point of interest to us is the evidence of a gradual progression towards a more and more complicated style of tuberculate molars that is to culminate in the multituberculate type of the most primitive mammals.

Trirachodon.—Of this genus Seeley says: "The skull in this genus has a most remarkable mammalian aspect, in form and proportion of every part. It was four inches long, as preserved, and about two inches wide behind. The orbits are circular, placed slightly in advance of the middle length of the head. The snout appears to terminate conically, rounded above and tapering forward, with a rounded alveolar margin. . . . . Each molar crown has three transverse, conspicuous ridges, but the middle ridge is the most elevated, and rises as a distinct cusp on the external and on the internal margins."

Microgomphodon.—This genus is known from the portion of a skeleton preserved in a slab of rock from the same region as the preceding genera. The teeth are the most characteristic portion; they are much enlarged in the transverse direction, being nearly or quite as long as wide. The surface is slightly convex from before backwards, and is covered with small tubercles, that become much larger at the external and the internal edges. The form is a small one, the largest teeth having a transverse diameter of two-tenths of an inch only and an antero-posterior

of one-tenth. The ribs are of the usual broad character of the African Permian reptiles generally, and the pelvis shows the broad ischium and pubis of the *Cynodontia*.

Gomphognathus.—This is perhaps the most interesting of the South African reptiles, because of its great similarity in structure to the *mammalia*. This is most apparent in the double occipital condyles, in the length of the separated nasal cavity, in the division of the teeth into premolars and molars, as well as into the major divisions of the dentition, the incisors, canines, and molars. The whole aspect of the skull is strikingly mammalian. The molar teeth have a posterior cusp or heel, and the outer edge is raised into a sharp cusp.

The geological and the geographical relations of this group are of extreme interest. They range in time only through the Permian and the Triassic. They are known only from a very limited region in South Africa, and from an even more limited region in the United States, where indeed the whole range of the fossiliferous beds is within the limits of four counties. Besides these two regions there is the case of the single tooth from the Wurtemberg region.

DINOSAURIA.—The *Dinosauria*, or the *Dinosaurs*, is the name applied to a large group of extinct animals that were confined to the Mesozoic time exclusively. When the existence of the group was first recognized by Owen, in 1839, he considered it as a well-defined order. Later discoveries have shown that under the original description there must be placed in the order animals of the most diverse character, so that it is becoming apparent that the old group must be abandoned and another, or, more correctly, several others, substituted. The very comprehensive character of the order, as usually defined, may be seen from the following characters given by Marsh, Zittel, Haeckel, and other writers on the group.

Premaxillary bones separate; upper and lower temporal arches present; no teeth on the palate; rami of the lower jaws united by cartilage only; vertebræ procœlus, opisthocœlus, or amphicœlus, sacral vertebræ united; scapula elongate; no pre-

coracoids; coracoid small; ilium greatly prolonged in front of the acetabulum; the ischia joining on the median line below; the pubis often with a strong posterior process, the post-pubic process. The form of the body and the head varies greatly in the different forms, being sometimes like that of the crocodiles and at other times like that of the birds, reptiles, or even the mammals. In the majority of the forms the hind limbs exceeded the anterior ones in size, and were used more commonly in walking; in some of the later and more specialized forms the anterior pair of limbs had lost the ambulatory functions entirely and had become wholly prehensile in character. The feet were as variously developed as the other parts of the body; in some of the forms inclining towards the ungulate type and in others developing well-formed claws. The dentition varied from the carnivorous to the herbivorous, some forms having strong recurved tusks, with serrated anterior and posterior cutting edges, and others with the jaws filled with close-set grinding teeth. The external appearance presented as many differences as the skeleton; in size they varied from that of the great herbivorous forms much larger than an elephant to the little leaping carnivorous forms no larger than a jack-rabbit. The skin of some was smooth and of others thickly covered with bony dermal plates and excrescences. Some walked erect, using the strongly developed tail as an aid in supporting the body, while others were entirely quadrupedal.

This great range of characters has led to a great number of different schemes of classification, in most of which the order *Dinosauria* has been recognized as a definite group, but it is constantly growing more difficult to keep the heterogenous assemblage together. Through all the later attempts at classification there has been a recognition of three types of structure that have been regarded as of ordinal, subordinal, or family rank by the various authors. These three divisions were regarded by Baur as distinct groups having nothing to do with each other.[1]

[1] BAUR, "Remarks on the Reptiles generally called Dinosaurs," American Naturalist, May 1891.

In his last classification of the *Dinosaurs*,[1] Marsh recognizes essentially the same group as Baur, but considers them as orders of the subclass *Dinosauria*. These three groups are called *Theropoda*, *Sauropoda*, and *Predentata;* the same groups were called by Baur *Megalosauria*, *Cetiosauria*, and *Iguanodontia*.

It is without the scope of the present article to discuss the intricate taxonomy of this group, and it will perhaps suffice to recognize the three distinct groups and to know that the tendency at the present is to consider the *Dinosauria* as an unnatural order and to speak of the *Dinosaurs* as a very loosely connected group made up of several distinct and well-defined groups.

THEROPODA (*Megalosauria*). — Brain case incompletely ossified in front; no ossified alisphenoid; an epipterygoid (columella); premaxillaries not excluding maxillaries from the nasal opening; jugal connected with the alveolar border of the maxillaries on the same plane; quadrato-jugal free from the maxillary; quadrate directly backwards; mandible without predentary bone; dentary without coronoid process; sacral vertebræ with the ribs joined intervertebrally; diapophyses of the vertebræ without connection with the ribs, but reaching out to and joining the ilium; pubes directed forward and strongly united at the distal end; limbs with the bones frequently hollow; posterior limbs much the largest; feet terminated by claws that are prehensile in the fore foot; locomotion mainly bipedal and digitigrade.

Anchisaurus, the oldest one of this group, as well as the oldest known *Dinosaur*, is from the Triassic Red Sandstone of the Connecticut Valley. A nearly perfect skeleton was obtained from these rocks in the vicinity of Manchester, Conn., in 1884. Previous to this time there had been fragments of skeletons obtained from the Triassic rocks of Pennsylvania and Prince Edward's Island, in Canada, as well as from the same deposits in the Connecticut Valley that in all probability belong to the same genus.

[1] "The Dinosaurs of North America," 16th Ann. Rept. of the Director of the U. S. G. S., Pt. I.

The skull was very birdlike in general outline; both the upper and lower jaws were full of small, sharp teeth that inclined toward the anterior ends of the jaws, and were not differentiated into molar and incisor regions (this feature occurs only in the most specialized of the reptilia); the fore limbs were much smaller than the hind limbs, but were quite large in comparison with these of the more specialized forms of later time, and perhaps took a large part in walking, although the hind limbs undoubtedly were the most largely used; all the bones of the limbs were hollow, and had very thin and solid walls, as in the birds; the fore foot had five digits, only four of which were functional; the hind limb had four toes on the foot, the fifth being a mere rudiment and the first much smaller than the others, so that the track would have been that of a three-toed animal. It is altogether probable that many, if not all, of the so-called bird tracks of the Connecticut Valley sandstone were made by these animals. One species had a length of nearly six feet, while another was much smaller, no larger than a "small fox."

Thecodontosaurus is one of the few European Triassic *Dinosaurs* that are known. It is from the Rhaetic of Bristol in England. The form is known from teeth and from portions of the skeleton; the teeth are of the typical carnivorous type, and are serrated on the anterior and the posterior borders.

Zanclodon (*Plateosaurus*) is from the Trias of many parts of Germany. The teeth are curved backward as in the preceding genus, and are serrated on the anterior and the posterior edges; the vertebræ are deeply bi-concave, and are very much longer and smaller in the cervical than the dorsal region; the limbs were short and strong and the jaws were long and curved. Only a part of the skeleton is known, although several specimens have been discovered; altogether there are about sixty vertebræ preserved in series, and these have a length of nine feet; the form is remarkable in being one of the few *Dinosaurs* that have bi-concave vertebræ.

Epicampodon is a form from the Trias of the East Indies,

Panchet group. It is known only from a few teeth having the same character as those of the previously described forms.

Massospondylus is the name given to certain remains from the Trias of South Africa, Karroo formation, and East India, Panchet group, that are known from a few teeth of the usual recurved type and some deeply bi-concave vertebræ.

Arctosaurus is from the northern part of North America, and is known only from a single vertebra.

Compsognathus from the upper Triassic of Bavaria, Lithographic Slates of Kelheim, was very similar in many respects to *Hallopus* of the Jurassic; the hind limbs were much smaller than the fore limbs, and the lower part of the leg showed the same adaptation to a leaping form of progression. The bones were all hollow and very compact in structure; the cervical vertebræ were numerous, forming a long neck, to which the head was joined at right angles. The astragalus was very closely joined to the end of the tibia, much as in the birds. Many authors have seen in this form the direct ancestors of the birds, but there are still wanting certain links to join the two forms together.

This closes the list of the well-known Triassic *Dinosaurs*. It will be noticed that they are all of the carnivorous type, though indications of a larger form of the herbivorous type are mentioned by Marsh. This author says of the distribution of the Triassic *Dinosaurs:* "It is a remarkable fact that the seven skeletons of Triassic *Dinosaurs*, now known from the eastern part of this continent, are all carnivorous forms and of small size. There is abundant evidence from large footprints that large herbivorous *Dinosaurs* lived here at the same time, but no bones nor teeth have yet been found. In the western part of the continent a few fragments of a large *Dinosaur* have been found in strata of supposed Triassic age, but with this possible exception osseous remains of these remains appear to be wanting in this horizon." Footprints "have been discovered in the Triassic sandstones of New Mexico. A few bones of a large *Dinosaur* were found by Professor Newberry in strata apparently of this age in southern

Utah. These remains were named by Professor Cope *Dystrophæus*."

Hallopus, from the Jurassic of Colorado, is remarkable for its development as a leaping form; the femur is much shorter than the fore part of the leg and the metatarsals are greatly elongated, as in the jumping rodents. The whole form was not much larger than a rabbit.

Cœlurus, from the upper Jurassic of Wyoming, was much larger than the preceding genera, being several feet in length. It was of the same jumping type, the fore feet being much the larger. The skull is very imperfectly known. The most remarkable thing about the skeleton is the thinness of the bones and the great cavities that exist in all of them, the ribs even being hollow. The limb bones, the vertebræ, the bones of the pelvis and of the pectoral girdle, are all excavated by large air cavities that must have rendered the skeleton very light. The dentition was of the same carnivorous type as the former genera.

Ceratosaurus, from the upper Jurassic of Colorado, is one of the largest of the *Theropoda*, being about seventeen feet in length. The head was very large in proportion to the body and was quite lizardlike in many respects; there was developed on the anterior portion of the snout a strong bony process that undoubtedly supported a horn during the life of the animal. The bones of the skeleton are very light, having internal cavities such as exist in *Hallopus* and *Cœlurus*, only to a less extent; the hind limb is much larger than the fore limb, so much greater that it is possible that the fore limb was never used for other purposes than those of seizing and holding the prey of the Dinosaur. The bones of the pelvis are anchylosed together, instead of showing the sutures between the bones as in the other forms; this is an essentially birdlike feature.

Allosaurus, *Creosaurus*, and *Labrosaurus* are all from the upper Jurassic of Wyoming and Colorado. The former was one of the largest carnivorous forms of the United States, if not the largest. The total length was about twenty-one feet. Remains that have

been referred by Marsh to these genera have been taken from the Potomac Beds of Maryland.

Lælaps was one of the same type of *Dinosaurs* as those already described It is from the upper Cretaceous of New Jersey and Montana. The animal had a length of about fifteen feet.

The European forms presented scarcely less varied types than the American forms, but the bones are less well preserved and the skeletons consequently less well known. Prominent ones are *Megalosaurus* and *Streptospondylus*. The first, from the Jurassic of England and many parts of the continent, is also known from the Jurassic beds of Colorado and from the Cretaceous of the East Indies. It was one of the largest of the *Theropoda*, the femur being over a meter in length.

Aristosuchus, from the Wealden of England, is somewhat similar to *Cœlurus*, having similar cavernous vertebræ and light limb bones

Tanystrophæus, from the Muschelkalk of Bayreuth, is remarkable for the extremely elongated cervical and caudal vertebræ. They are eight or ten times as long as they are broad, and are hollow as in *Cœlurus*. The same form is known from the Triassic rocks of New Mexico.

SAUROPODA (*Cetiosauria*).— Brain case completely ossified in front; a well developed alisphenoid; no epipterygoid (columella); premaxillaries not excluding the maxillaries from the nasal opening; jugal and quadrate forming a continuation of the posterior border of the maxillary in the same plane; quadratojugal in connection with the maxillary: quadrate directed forward; mandible without predentary bone; dentary without coronoid process; sacral ribs attached to a single vertebra; neural canal much expanded in the sacrum; limb bones without medullary canal; the fore and hind limbs nearly of the same size; feet plantigrade; the termination of the toes in nails or hoofs rather than in claws.

The order is practically unknown in Triassic time, but in the

Jurassic reached a very great development, both in numbers and in diversity of forms.

Brontosaurus is from the upper Jurassic, in the vicinity of Lake Como, in Wyoming. It is the largest *Dinosaur* known, as well as the largest of the animal creation; the whole beast, from tip of snout to tip of tail, measured nearly sixty feet. The head was very small in proportion to the rest of the body, being less than the fourth cervical in size. The tail and the neck were long and quite strong. The tail was over half as long as the rest of the body; the dorsal vertebræ had a short antero-posterior extent, but were quite broad. A hole under the transverse process of each side opened into a large cavity in the body of the vertebra, probably for the purpose of reducing weight. The pectoral girdle is represented by the usual elements, but the coracoid is very much smaller than the scapula and the sternum is composed of two pieces, one on each side of the median line as in the embryos of birds. The neural canal is greatly enlarged in the sacral region; this enlargement begins even in the cervical region, so that it would have been possible to have drawn the whole of the brain down through the neural canal.

It is difficult to see how an animal that had reached the unwieldy size of the *Brontosaurus* could have supplied itself with food; the very small head and rather weak dentition would seem to render the actual task of getting a sufficient supply of food into the enormous body a very difficult one, even granting that the food was most plentiful; but if the animal was compelled to search to any extent for its supplies the work must have been an almost constant one. This is especially true because the food was entirely vegetable, and the proportion of such food necessary to support a body is much greater than the more condensed food of the carnivorous forms. The animal was in all probability semi-aquatic in its habits and lived for a good part of the time in the waters of the oceans and the lakes of the later Jurassic and the early Cretaceous time. That they suffered much from their great bulk is evident from the condition in which the skeletons are found; they are in many cases complete and undisturbed,

showing that the animal was mired down in some hole or on the uddy bank of some body of water.

Camarasaurus (*Atlantosaurus*) was very similar to the preceding, differing in the fact that the sacral and the caudal vertebræ are solid, instead of having the large vacuities that are found in the same bones of the preceding genus and in the vertebræ of the anterior region of this genus. The scapula of one specimen measured one and a half meters, and the femur nearly two. From the Upper Jurassic of Colorado.

Morosaurus, *Allosaurus*, and *Apatosaurus* are all forms that are distinguished by minor characters of the vertebræ, and limbs from the preceding genera. They are all from the same horizon as the preceding, in Wyoming and Colorado.

Cetiosaurus is from the Upper Jurassic of England ; the form is so similar to that of the various American forms that Baur has suggested that all the genera from Colorado and Wyoming are possibly the same as the English one. The skeleton is only partially known, the head being missing in all the known specimens. It was nearly thirty-five feet in length, with about the same proportions of the fore and hind limbs, and the vertebræ as *Brontosaurus*.

Ornithopsis, from the Upper Jurassic of England and France is very similar to *Cetiosaurus*, but shows large vacuities in the sides of the dorsal vertebræ.

Diplodocus, from the Upper Jurassic of Colorado and Wyoming, is remarkable for the long cervical and caudal vertebræ. The vertebræ were very light and hollow, those of the sacral region especially. The chevron bones, instead of being simple, with only the single V-shaped branch, were composed of two V-shaped branches that extended forward and back, and were united at the proximal extremities. The jaws were edentulous, except at the anterior ends, and these were supplied with long, slender teeth that were constantly shed and renewed from below, a specimen with as many as seven successive teeth in various stages of development being known.

Titanosaurus is the name given to certain large vertebræ, from

the Middle Cretaceous layers of the East Indies. The same vertebræ have been found in the Cretaceous of England.

A very imperfectly known form, *Aepysaurus*, is found in the Cretaceous of France.

Imperfect remains have been described from Patagonia, *Argyrosaurus* and *Titanosaurus*, and from Madagascar *Bothriospondylus*.

Some teeth and parts of vertebræ have been discovered in the upper part of the Potomac formation of Maryland.

It will be seen that the *Sauropoda*, as far as we know them now, are for the most part confined to the continent of North America. The few forms that are found in the other parts of the world indicate the wide extension of the group, but in these there is no indication of such a degree of specialization as was attained by the North American forms. This continent seems to have been the home of the group and the seat of their greatest development.

PREDENTATA (*Iguanodonta*).— Brain case completely ossified; a well-developed alisphenoid; no epipterygoid (columella); premaxillaries, with a posterior outer process extending between the maxillaries and the nasals, excluding the maxillaries from the nasal openings; jugals fixed to a special process outside of the alveolar process of the maxillaries; posterior border of the maxillaries free, not attached to the jugal or the quadrato-jugal; quadrate directed forward; the anterior end of the mandible furnished with a distinct predentary bone; dentary with a greatly developed coronoid process; sacral vertebræ, with the ribs and the diapophyses attached, and the ribs joined to two vertebræ (intervertebrally); pubis consisting of two branches, the anterior one, ectopubis (pectineal process, prepubis) extending far forward and joined with the one of the opposite side by suture; the posterior one, the entopubis, extending far backward, and lying parallel to the ischium, is well developed in some forms, but in others rudimentary; illium much extended in front of the acetabulum, and also reaching far behind. In some forms of this suborder the fore and hind limbs were of nearly equal size,

while in others the hind limbs were nearly as large in proportion to the front limbs as in the *Theropoda;* the feet were armed, in the majority of cases, with flat claws, or hoofs. The dentition shows that the animals were herbivorous in diet, and the mouth is, in some forms, crowded full of teeth. This group did not develop the enormous size of the preceding group, but sought protection in the development of a bony armature that rendered them, in many cases, safe from the attacks of the carnivorous forms.

Stegosaurus.—The jaws were furnished with teeth in the posterior portion only, the premaxillaries being edentulous and probably covered with a horny beak that served the animal in gathering the plants which formed its food. The teeth were flattened sideways, and the crowns were serrated; the limbs, bones, and the vertebræ were solid; the fore and hind limbs were of the same size; the neural processes of the dorsal vertebræ were quite high, and supported the ribs from near the apex; the feet were plantigrade, and the toes terminated in broad, hooflike claws. The most remarkable thing about the form was the fact that there were developed in the skin of the back and sides great, broad plates of bone that possibly stood up as a median ridge along the back. All the known specimens are from the Upper Jurassic of Colorado and Wyoming.

Camptosaurus, *Laosaurus*, *Dryosaurus*, and *Nanosaurus* are all from the same horizon and the same localities as *Stegosaurus*. They resemble that form in the arrangement of the pelvis, the bones of the skull, and all the essential features of the group, but differ in many external characters. The hind limbs are much larger than the fore limbs, and seem to have monopolized the function of progression; the fore feet are very small, and could only, under peculiar circumstances, have served as organs of locomotion. There were five functional digits on the fore feet and only three on the hind foot, so that the tracks would have been the same as those of a large bird, and it is very probable that the tracks in the Triassic sandstone of the eastern part of the United States may be tracks of these or of related forms,

instead of birds, as originally supposed. The bones are all hollow, and the whole skeleton was very light. There was an almost complete absence of the dermal armor that characterized the *Stegosaurus;* the whole lightness of the skeleton is incompatible with the weight of such a covering, and it is likely that the animals sought safety in flight, where the former genus trusted to the impenetrability of its armor. The largest of the four genera, *Camptosaurus*, was about twenty feet long, and the smallest, *Nanosaurus*, was only three or four. The last genus is the lightest and the most birdlike of all the *Dinosaurs.*

Dystrophæus is the name given by Cope to the incomplete remains of a *Dinosaur* from the Triassic rocks of Utah. There is preserved only the portions of the hind limb but these show that the animal had only three functional digits on the hind foot and that it was closely related to the *Camptosaurus.*

Teeth from the Potomac formation, evidently belonging to this group have been described by Marsh and Leidy as *Priconodon* and *Paleoscincus.*

Euskelosaurus from the South African beds is too incomplete to be definitely placed anywhere, but is generally placed among these forms.

Scelidosaurus is from the lower Lias of Dorsetshire in England. It was very similar in many respects to *Stegosaurus*, having the same quadrupedal locomotion and the same solid form of the bones but the dermal armor was reduced to a single row of small ossicles down the median line of the back. The whole form was nearly twelve feet long.

Agathaumus from the Upper Cretaceous of Wyoming, is one of the most peculiar of this peculiar group of animals; with the same bodily characters of the trunk as the *Stegosaurus*, minus the dermal plates, the interest of the form centers in the enormous development of the protective armature of the skull. The bones of the posterior cranial region were developed as an enormous cape that extended back over the shoulders; around the edges of the cape there was a series of smaller bones. The frontal portion of the superior aspect of the skull was protected by the

development of three large horns, two of these, the largest, projected from the superior edges of the orbital rims, the others from the anterior part of the snout. One skull taken from the Laramie Cretaceous of Converse county Wyoming, was eight feet from the tip of the snout to the tip of the posterior edge of the skull, and weighed, with the matrix of sandstone, 3600 pounds. The teeth were set in a single row in the jaws and were provided with two roots, a rather peculiar condition in the reptiles. The teeth were transverse and presented broad grinding surfaces. The whole body was stout and elephantine in proportions; the skin was undoubtedly furnished with small dermal ossifications spread through its surface. The tail was long and heavy. The animal must have been, according to Marsh, twenty-five feet long and about ten high.

Torosaurus from the same horizon as the last was smaller, but still quite large, as one skull measured five and a half feet across the top. The most remarkable thing about this form was the great posterior development of the capelike portion of the skull. It extended much farther back than in *Agathaumus* and was perforated by two large fontanelles in the posterior part. The whole plate is much thinner than in the other form.

Claosaurus is from the same region as the preceding and bears about the same relation to those forms that *Scelidosaurus* does to *Stegosaurus*, that is, the general characters of the body are the same, but the peculiar specialization has disappeared. This animal developed the posterior limbs at the expense of the anterior ones, as organs of locomotion. Oddly enough the front feet did not assume the function of grasping organs as in the *Theropoda*, which assumed the bipedal form of locomotion, but retained the broad terminal phalanges that indicate the possession of hoofs on the front feet even after they had grown so short that they could not have reached the ground. The hind feet possessed three functional digits as in *Agathaumus*. The mid-dorsal series of vertebræ was strengthened by the presence of many long ossified tendons that extended for some distance on each side of the neural spines. The limb bones were solid.

The whole animal attained a length of about thirty feet and was probably about fifteen high when it stood erect.

Hadrosaurus is from the same region as all the forms just described and presents the peculiar feature of a flattened snout, resembling the bill of a duck, or the snout of the Australian mammal, *Ornithorhynchus*. Only the skull is well known. The anterior ends of the jaws were edentulous, and were probably covered by a horny sheath; the posterior portions were filled with a large number of teeth that were disposed in rows, and were successional in arrangement so that as fast as the old teeth were worn out new ones, developed in the sides of the jaw, came in to take their places. In one specimen Cope counted six hundred and thirty teeth on each side of the upper jaw and four hundred and six on each side of the lower jaw, making a total of two thousand and seventy-two. The animal was probably aquatic in its habits of feeding, and used the ducklike bill much as the bottom feeding aquatic birds do in gathering up the ooze and slime that contain their food. The fragments of the skeleton that are known indicate that the animal had the same relative proportions of the fore and hind limbs as *Claosaurus*.

Agathaumus, most generally, but erroneously, called *Triceratops*, *Torosaurus*, *Claosaurus*, and *Hadrosaurus* are all from the Upper Cretaceous, the Laramie, and from a very limited region in the northeastern portion of Converse county in Wyoming. A few remains of these forms have been found in near-by portions of Wyoming and Montana.

Iguanodon is the European representative of the *Predentata*. It is one of the few members of the group found outside of the United States. It was of the bipedal type, the hind feet being larger than the fore feet and the whole hind limb showing the more robust character so common in the American forms. There were three functional toes on the hind foot and three on the fore foot, but there were two, the first and the fifth, on the fore foot that are entirely lacking on the hind foot. The first digit on the fore foot was modified in a most peculiar manner into a short and strong spurlike process that stood out at right angles to

the rest of the digits. The vertebral column was strong with well developed neural processes on the dorsal vertebræ which were further strengthened by ossified tendons that aided in moving the heavy tail. The postpubis was long and extended back almost to the distal extremity of the ischium. The teeth were of the same type as the American forms, broad laterally, with serrated edges, and adapted to the trituration of vegetable food. There was no dermal armor as far as known but it is possible that there were small bony ossicles developed in the skin. The animal reached a length of thirty feet in the largest genus and about half of that in the smallest. It is known from the Wealden of England and France, the most important deposit, however, is from the same horizon in the neighborhood of Bernissart, in Belgium, from which region a large number of skeletons have been taken, the majority of them in a very perfect state of preservation.

A description of the *Dinosaurs* would not be complete without some mention of the fossil tracks in the Triassic sandstones of the eastern part of the United States. These are typically developed in the rocks of the Newark group in the valley of the Connecticut River, and are also found in these same rocks where they appear in Pennsylvania, Virginia, and North Carolina. A very large number of these impressions have been taken from the Connecticut region, and over a hundred separate species have been named from them. They are almost all three-toed forms and range from about an inch in length to over a foot. They are found associated with amphibian tracks. The course of the tracks may, in some instances, be traced for many feet or yards, and the length of stride and the character of the feet of the two sides can be clearly made out. The majority of the impressions show that the animals walked on the hind feet most of the time, only occasional traces of the front feet being found. In some cases a long groovelike track indicates where the tail of the animal was dragged through the mud. Because of the three-toed character of the tracks and the peculiar resemblance to the tracks of birds they were originally described by Hitchcock as bird tracks (*Ornithichnites*).

Translating very freely from Zittel's *Handbuch*, we have the following summary of the range and distribution of the *Dinosaurs:*

In general we may say that Europe and North America were, during the Triassic, Jurassic, and Cretaceous times, the home and the region of the greatest development of the *Dinosaurs*. From the East Indies only incomplete remains are known from the Trias and the Cretaceous, and from South Africa, only enough remains to say that there were *Dinosaurs* there. In South America and Australia the remains of these animals are, as yet, completely unknown.

Although the largest number of forms as well as the most perfectly preserved remains are known from the United States, Europe affords many specimens of all the principal groups. The American *Sauropoda* are represented in Europe by *Cetiosaurus, Ornithopsis* and an incompletely preserved Cretaceous form. The *Zanclodontidæ* parallel to some extent the *Anchisauria*. The *Megalosauria* of Europe are represented in this country by *Allosaurus, Lælaps*, and several less well-known forms. The *Ceratosauria* are unknown in the Old World, and the *Cœluria*, hollow-boned forms, are represented by *Calamospondylus* and *Aristosuchus*. *Tanystrophæus* belongs to both the Old and the New Worlds. The European *Compsognathus* is found in the *Hallopus*. Among the *Predentata* the *Scelidosauria* are confined to Europe while the *Stegosauria* are mostly American. *Omosaurus*, if not a synonym of *Stegosaurus*, would be a European representative of this group. The forms from the Laramie Cretaceous are all confined to the American continent.

From a geological standpoint the original distribution of the *Dinosaurs* was practically contemporaneous, though even in the Trias there were well defined areas containing differentiated forms, and this differentiation by local development was accentuated in the Jurassic and Cretaceous. Animals from the two continents frequently belong to the same families but seldom to the same genera and species.

Perhaps the most peculiar thing about these forms is the sudden and complete destruction of the whole order at the end of the Mesozoic time. The Cretaceous rocks just at the end of the period show that there was a very large number of individuals as well as species, but the earliest of the Tertiary series are as free from their remains as the most recent formation. There is no cause for this sudden extinction of a great group unless it was a climatic one, and even this is not indicated by any change in the vegetable life of the two periods.

Below is a list of the various genera of the Dinosaurs arranged to show their systematic and time relations.

	Triassic	Jurassic	Cretaceous
THEROPODA	*Anchisaurus*	*Cælurus*	*Lælaps*
	Zanclodon	*Ceratosaurus*	*Ornithomimus*
	Epicampodon	*Allosaurus*	*Megalosaurus*
	Massospondylus	*Labrosaurus*	
	Arctosaurus	*Creosaurus*	
	Tanystrophæus	*Megalosaurus*	
		Streptospondylus	
		Aristosuchus	
		Compsognathus	
		Hallopus	
SAUROPODA		*Brontosaurus*	
		Camarosaurus	
		Morosaurus	
		Apatosaurus	
		Cetiosaurus	
		Ornithopsis	
		Diplodocus	
		Titanosaurus	
PREDENTATA	*Dystrophæus*	*Stegosaurus*	*Agathaumus*
	Euscelosaurus	*Camptosaurus*	*Torosaurus*
		Laosaurus	*Claosaurus*
		Dryosaurus	*Hadrosaurus*
		Nanosaurus	
		Scelidosaurus	

E. C. CASE.

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Baur, G. Remarks on the Reptiles Generally called Dinosauria. Am. Nat., May 1891.

Ballou, W. H. Strange Creatures of the Past. Century Magazine, November 1897. (Contains many good illustrations of Dinosaurs.)

EDITORIAL.

THE fiftieth anniversary of the American Association for the Advancement of Science was held at Boston, August 22 to 27. The total enrolled attendance was 903, new members 273. The number of papers read before the Geological Section was 29; before the Geological Society 19; before the National Geographic Society 8; making the total of geologic and geographic papers 55.

The titles of the papers were as follows:

VICE PRESIDENTIAL ADDRESS.

Glacial Geology in America. By Professor H. L. FAIRCHILD, Rochester, N. Y.

BEFORE THE GEOLOGICAL SOCIETY OF AMERICA.

1. Some Features of the Drift on Staten Island, N. Y. By ARTHUR HOLLICK, Columbia University, New York, N. Y.

2. Loess Deposits of Montana. By Professor N. S. SHALER, Cambridge, Mass.

3. Glacial Waters in the Finger Lake Region of New York. By Professor H. L. FAIRCHILD, Rochester, N. Y.

4. The Stratification of Glaciers, with lantern views. By H. F. REID, Baltimore, Md.

5. Evidences of Epeirogenic Movements Causing and Terminating the Ice Age. By WARREN UPHAM, St. Paul, Minn.

6. Clayey Bands of the Glacial Delta of the Cuyahoga River at Cleveland, O., compared with those in the Implement-bearing Deposits of the Glacial Delta at Trenton, N. J., with lantern views. By Professor G. FREDERICK WRIGHT, Oberlin, O.

7. The Middle Coal Measures of the Western Interior Coal Field. By H. FOSTER BAIN and A. T. LEONARD, Des Moines, Ia.

8. The Principal Missourian Section. By CHARLES R. KEYES, Des Moines, Ia.

9. Tourmaline and Tourmaline Schists from Belcher Hill, Jefferson county, Colo. By HORACE B. PATTON, Golden, Colo.

10. Magmatic Differentiation in the Rocks of the Copper-bearing Series. By ALFRED C. LANE, Houghton, Mich.

11. The Volume Relations of Original and Secondary Minerals in Rocks. By Professor CHARLES R. VAN HISE, Madison, Wis.

12. Note on a Method of Stream Capture. By ALFRED C. LANE, Houghton, Mich.

13. The Development of the Ohio River. By Professor WILLIAM G. TIGHT, Granville, O.

14. Classification of Coastal Forms. By F. P. GULLIVER, Southboro, Mass.

15. Dissection of the Ural Mountains, with lantern slides. By F. P. GULLIVER.

16. Note on Monadnock. By F. P. GULLIVER.

17. Spacing of Rivers with Reference to the Hypothesis of Base Leveling. By Professor N. S. SHALER, Cambridge, Mass.

18. The Continental Divide in Nicaragua. By C. WILLARD HAYES, Washington, D. C.

BEFORE THE GEOLOGICAL SECTION OF A. A. A. S.

1. Outline Map of the Geology of Southern New England. By Professor B. K. EMERSON, Amherst, Mass.

2. Basins in Glacial Lake Deltas. By Professor H. L. FAIRCHILD, Rochester, N. Y.

3. An Exhibition of the Rare Gems and Minerals of Mt. Mica. By Dr. A. C. HAMLIN, Bangor, Me.

4. The Hudson River Lobe of the Laurentide Ice-sheet. By Professor C. H. HITCHCOCK, Hanover, N. H.

5. The Age of the Amboy Clay Series as Indicated by its Flora. By Professor ARTHUR HOLLICK, Columbia University, New York, N. Y.

6. Some Feldspars in Serpentine, Southeastern Pennsylvania. By Professor T. C. HOPKINS, State College, Pa.

7. The Region of the Causses in Southern France, with maps and stereopticon views. By Dr. HORACE C. HOVEY, Newburyport, Mass.

8. The Washington Limestone in Vermont. By Professor C. H. RICHARDSON, Hanover, N. H.

9. Fluctuations of North American Glaciation shown by Interglacial Soils and Fossiliferous Deposits. By WARREN UPHAM, St. Paul, Minn.

10. Time of Erosion of the Upper Mississippi, Minnesota, and St. Croix Valleys. By WARREN UPHAM.

11. Supposed "Corduroy Road" of Late Glacial Age at Amboy, O. By Professor G. FREDERICK WRIGHT, Oberlin, O.

12. Changes in the Drainage System in the Vicinity of Lake Ontario during the Glacial Period. By Dr. M. A. VEEDER, Lyons, N. Y.

13. Recent Severe Seismic Movements in Nicaragua. By JOHN CRAWFORD, Managua, Nicaragua.

14. Another Episode in the History of Niagara River. By J. W. SPENCER, Washington, D. C.

15. The Age of Niagara Falls as Indicated by the Erosion at the Mouth of the Gorge. By Professor G. FREDERICK WRIGHT, Oberlin, O.

16. A Recently Discovered Cave of Celestite Crystals at Put-in-Bay, O. By G. FREDERICK WRIGHT.

17. Geography and Resources of the Siberian Island of Sakhalin. By Professor BENJAMIN HOWARD, London, Eng.

18. Evidence of Recent Great Elevation of New England. By J. W. SPENCER, Washington, D. C.

19. The Oldest Palæozoic Fauna. By G. F. MATTHEW, St. John, N. B.

20. The Oldest Known Rock. By Professor N. H. WINCHELL, Minneapolis, Minn.

21. The Origin of the Archæan Igneous Rocks. By Professor N. H. WINCHELL.

22. Joints in Rocks. By Professor C. R. VAN HISE, Madison, Wis.

23. Notes on Some European Museums. By Dr. E. O. HOVEY, New York, N. Y.

24. History of the Blue Hills Complex. By Professor W. O. CROSBY, Boston, Mass.

25. Palæontology of the Cambrian Terranes of the Boston Basin. By AMADEUS W. GRABAU, Boston, Mass.

26. Diamonds in Meteorites. By Mrs. E. M. SOUVIELLE, Jacksonville, Fla.

27. The Periodic Variations of Glaciers. By Professor HARRY F. REID, Baltimore, Md.

28. Note on the Occurrence of Tourmalines in Canada. By C. R. ORCUTT, San Diego, Cal.

29. The Agassiz Geological Explorations in the West Indies. By ROBERT T. HILL, Washington, D. C.

BEFORE THE NATIONAL GEOGRAPHIC SOCIETY.

1. The Venezuela-British-Guiana Boundary Dispute. By Dr. MARCUS BAKER, Washington, D. C.

2. Considerations Governing Recent Movements of Population. By JOHN HYDE, Washington, D. C.

3. Some New Lines of Work in Government Forestry. By GIFFORD PINCHOT, Washington, D. C.

4. The Development of the United States. By W J MCGEE, Washington, D. C.

5. Atlantic Estuarine Tides. By M. S. W. JEFFERSON.

6. The Forestry Conditions of Washington State. By HENRY GANNETT, Washington, D. C.

7. The Five Civilized Tribes and the Topographic Survey of Indian Territory. By CHARLES H. FITCH, Washington, D. C.

8. Bitter Root Forest Reserve. By RICHARD U. GOODE, Washington, D. C.

The foregoing has been kindly furnished by Mr. Warren Upham, secretary of Section E, A. A. A. S.

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GEOLOGISTS visiting the exposition at Omaha, and teachers everywhere, will find particularly valuable the topographic map of Omaha and vicinity, published by the United States Geological Survey and gratuitously distributed in the Mines and Mining building. The map bears the date of June 1898, and is an example of the excellence of the maps now being made. The main features are the Missouri River bottom land and valley, and the loess topography. The former is a most characteristic bit of river work. The cut-off lakes, the great bends of the river, the sharp bluffs where the stream impinges against the bank, and other features are shown so clearly as to make the map especially valuable in the class-room. The apparent similarity in width of the Platte and the Missouri rivers and the dissimilarity in their valleys, will likewise call forth questions.

It is, however, the loess topography which is most interesting, since within the limits of the quadrangle there is an excellent example of the contrast between the wind-shaped loess near, and the water deposited away from, the vicinity of the stream. On the west side of the river, in Omaha and near it, the map shows open contour, gentle slopes, and obvious erosion topography and a rectangular system of roads. The hills rise easily to 1200 or 1250 feet A. T. Immediately across the river the contours are close, the slopes sharp, the roads follow streams and ridges and disregard land lines, and the hills rise abruptly to 1300 or 1350 feet, A. T. A very characteristic feature, well shown on the map, is the large number of small detached peaks. Another is the interference

with the drainage, as for example in the case of Mosquito Creek. This stream, whose valley is followed by the Chicago, Rock Island and Pacific, and the Chicago, Milwaukee, and St. Paul railways, has a quite well developed flood plain and a broad, open valley in its upper portion. As it comes within the influence of the river loess, the valley is choked and becomes a mere narrow defile. This and the other features mentioned are not exceptional, but are found at quite distinct points along the Missouri,[1] and are of considerable significance in the matter of genesis of the loess. There are numerous other items of interest relative to the map, but sufficient has perhaps been said to call attention to its value.

H. F. B.

[1] Geology Plymouth county, Iowa Geol. Surv., Vol. VIII, 1898, pp. 324–332.

Reviews.

STRATIGRAPHY OF THE SOUTHERN OZARKS.

Thickness of the Palæozoic Sediments in Arkansas. By John C. Branner. Am. Jour. Sci., (4), Vol. II, pp. 229-236, 1896.

Batesville Sandstone of Arkansas. By Stuart Weller. Trans. New York Acad. Sci., Vol. XVI, pp. 251-282, 1897.

Marine Fossils from the Coal Measures of Arkansas. By James Perrin Smith. Proc. American Philos. Soc., Vol. XXXV, pp. 213–273, 1897.

Geological Reconnaissance of the Coal Fields of the Indian Territory. By Noah Fields Drake. Proc. American Philos. Soc., Vol. XXXVI, pp. 326-419, 1898.

A decade ago one of our most distinguished writers on geology, commenting upon the progress of geological investigation in this country, drew special attention to the mountainous region of the central Mississippi basin by making the startling statement that that part of our national domain about which least was known geologically was not in the rugged ridges of the Appalachians nor in the great cordilleras of the Far West, but in the very heart of the American continent, in a district where mining had long been carried on — in the Ozark region. Surprising as was the statement it was literally true. Up to that time there had been practically nothing on the geology of this region published. There was no place to which one could turn for information regarding the geology of a tract of more than 100,000 square miles.

Singularly enough, as if anticipating the full force of the remark alluded to, and before the paragraphs had left the press, the states of Arkansas and Missouri established geological surveys the express purposes of which were to solve this very problem. As the result of these official activities there have been published by the two states mentioned

upwards of twenty-five large volumes, all of which are devoted, wholly or in part, to the geology of the Ozarks.

Growing out of this official work, either directly or indirectly, there have appeared from time to time other contributions to a geological knowledge of the region. The Arkansas geologists have been especially active in setting forth information of the greatest value concerning the *terra incognita* of only ten years ago. Branner, Winslow, Penrose, Hopkins, J. F. and H. S. Williams, and Griswold have all given us geological accounts of great interest. The results of their work have been most acceptable. An outgrowth of this same work has been to induce others to take up attractive lines of investigation thus pointed out. At intervals there have been given short sketches that fill in important gaps.

Isolated from all localities where similar rock successions were already carefully studied and were well known, the workers in Arkansas were obliged to set up a geological rock classification of their own. The sequence of terranes could be correlated with those of well-known regions only in the most general way. Much has been done of late to clear up the existing uncertainty of stratigraphic equivalency. The early Palæozoic rocks still resist all attempts of detailed classification and correlation. The Carboniferous has yielded more gracefully. With the latest contribution, by Drake, the last link binding the stratigraphy of the southern region to the northern has been forged.

The "Thickness of the Palæozoic Sediments in Arkansas," by Professor Branner, may be taken as a concise summary of the results of the Arkansas geological survey regarding the sequence and development of the older rocks of the southern Ozarks. The article is accompanied by a small but excellent general geological map of the state, and gives a classification of the formations recognized, and their observed thicknesses. The enormous estimated thickness of the Coal Measures is especially noteworthy. These figures come somewhat in the nature of a surprise, manifestly to the author also, for he takes particular pains to present clearly the detailed evidence upon which he has reached his conclusions. He says: "There is, of course, nothing remarkable about the thickness of any of the Arkansas sediments except in the case of the Lower Coal Measures. So far as I can learn the thickness of the Carboniferous rocks in this section is greater than that of the sediments of the same age in other parts of the country or of the world."

The general section of the Palæozoic sediments is as follows:

Coal Measures or Pennsylvanian	Upper Coal M.	Poteau beds Productive beds	3500 1800
	Lower Coal M.	Barren beds	18480
	"Millstone grit"	. . . .	500
Lower Carboniferous, or Mississippian	Chester, St. Louis, Warsaw	Boston group	780
	Keokuk-Burlington	Batesville sandstone Fayetteville shale Wyman sandstone Boone chert	200 300 10 370
Devonian ?		Sylamore sandstone Eureka shale	40 50
Upper Silurian		St. Clair marble	155
Lower Silurian		Izard limestone Underlying beds	285 1750
			28220

The "Marine Fossils from the Coal Measures of Arkansas," by Dr. Smith, is largely a description of species, with comments upon their biologic relationships. Nevertheless, in the introductory portion, the stratigraphy is considered, and the conclusions reached concerning the position of the beds in the general geological column, as thought to be indicated by the fossil evidence, are set forth.

A table is given correlating the Arkansas strata with the Carboniferous deposits of China, India, Russia, South America, and other parts of the world. Done in such a broad way, it is hard to see just what force any extended discussion of this kind can have. Such faunal comparisons are, in general, of great interest in a biological way, and evidence a wide acquaintance with palæontological literature, but, from a geological standpoint, they have, with no reflection on Dr. Smith's efforts, small stratigraphic value. A detailed parallelism with its nearest related areas of Coal Measures, which is the great desideratum to all those at all interested in the geology of the region, and

which appears to have been, in starting out, the main object of the memoir, is the very phase that all would have desired to have discussed more fully. This, however, should not be expected, perhaps, since it pertains more particularly to the purely geological side of the question, and the paper lays most stress on the biologic aspects.

The account of the fossils is a welcome addition to our knowledge of the distribution of the Carboniferous organisms in the Mississippi province. While the list may appear meager, it must be remembered that heretofore only an occasional or straggling form was known from the region. Twenty-one localities yielded fossils. There are represented forty-eight genera and ninety species, some of which are not specifically identified. The "fauna is a poor one, such as one would expect to wander in from deeper waters whenever a slight subsidence made shallow waters a little more habitable. The faunas could not become well established, because the conditions soon reverted to their old state, and the inhabitants of the seas were forced to migrate or be exterminated."

In comparing the fauna with its nearest ally, in Kansas and Nebraska, the conclusion is reached that "there is not sufficient reason for classing the Poteau Mountain beds with the Permian, but their fauna, as well as stratigraphic position, place them very high in the Coal Measures, since they are like the fauna and position of the Mississippi Valley Upper Coal Measures."

The "Batesville Sandstone of Arkansas," by Mr. Weller, treats of the Lower Carboniferous of the northern part of the state. While the greater part of the paper is devoted to the description of fossils, the brief account of the stratigraphy and correlation features is the most important that has yet appeared on the subject. The comparison of the general section of the Lower Carboniferous in Arkansas with that of the typical localities along the Mississippi River shows that the two are essentially identical.

The "Batesville sandstone has the same stratigraphic position in the Batesville section which the Aux Vases sandstone occupies in the typical section, and the lithological characters of the two formations are similar. No fossils have as yet been found in the Aux Vases sandstone, but if a fauna were found a mingling of St. Louis and Kaskaskia species, such as are present in the Batesville sandstone fauna, would be looked for."

The parallelism of the Arkansas section of the Lower Carbonifer-

ous, or Mississippian series, with the one long known farther northward, is as follows:

Typical Mississippi Section	Arkansas Section
Kaskaskia limestone	Boston group
Aux Vases sandstone	Batesville sandstone
St. Louis limestone	Spring Creek limestone
Augusta limestones	Boone chert
Kinderhook beds	{ St. Joe marble
	{ Sylamore sandstone

According to this arrangement the former lines of division in the Arkansas formations will have to be modified considerably. The Kinderhook portion will doubtless need further revision in northern Arkansas.

A "Geological Reconnaissance of the Coal Fields of Indian Territory," by Dr. Drake, connects the Arkansas work with that of Kansas and Missouri. For the first time we are able to understand what relationships the subdivisions that were adopted by the Arkansas geologists, for the Coal Measures, have to those recognized in other parts of the interior province. The sketch-map accompanying the memoir gives the distribution of the formations; and a number of sections still farther elucidate the structure of the region.

A small crystalline area, the Spavinaw granite, discovered by Owen forty years ago, is found to be a dike, fifty feet wide, breaking through the crest of a low anticline of Silurian limestone. As, however, the overlying Lower Carboniferous in the bluffs a few yards away is also tilted in the same way as the Silurian strata, the age of the dike is regarded as post-Carboniferous. Since Owen mentioned the occurrence nothing further has been made known concerning this granite until the recent visit. The results of this examination are important, as they set to rest much speculation. As the granite must have been intruded under a considerable weight of superincumbent strata, it is somewhat surprising that all traces of metamorphic action should have escaped notice. The presence of the epidote would indicate that contact phenomena should be present, at least, in some slight degree.

The Silurian rocks appear only in a few limited areas in the extreme eastern part of the territory. All of these localities are north of the Arkansas River. Areas known to exist in the southern portion of the territory are omitted.

The Lower Carboniferous is well represented, the western boundary being approximately the Neosho River. The beds are continuous with those of northwestern Arkansas and southwest Missouri. The subdivisions recognized are the Eureka shale, Boone chert, Fayetteville shale, Batesville sandstone and the Boston group.

The rest of the Carboniferous is subdivided into Lower Coal Measures, Upper Coal Measures (with two groups, the Cavaniol or coal producing, and the Poteau or barren) and Permian.

The remainder of the paper is taken up with lists of fossils, some descriptions of new species, and a short economic chapter.

The restriction of the term Ozark to the northern part of the uplifted region of Missouri and Arkansas is noticeable. It is, no doubt, convenient to distinguish the northern, slightly folded part from the southern, trans-Arkansas portion, and to designate the latter the Ouachita region. The latter term will be generally used. This should not, however, be to the exclusion of some other name for the whole of the elevated area. The use of Ozark in the restricted sense as has been done, without giving any geographical reason, at once arbitrarily subdivides the region. The uplift, or dome, is believed to be a great geographic unit, having a definite history that covers the Ouachita district the same as the more northern area. From a geographic standpoint the close folding has no especial influence in the general development nor in determining its broad physiographic nature.

If the two districts are really distinct in their present aspects, when viewed from the genetic and geographic points of vantage, it should be shown that their development is in no way connected, that the history of each has been different, that their present physiognomies are of diverse origin. This has not been done as yet; and no attempt appears ever to have been made in this direction.

On the other hand all the published materials and the known facts seem to point to a very different course of events. After the Carboniferous the region between the Missouri and Red rivers was apparently subjected to orogenic movements—intense and local in the south, moderate and regional in the north. The whole region was then planed down during the Cretaceous or Tertiary, perhaps, practically base-leveled, so as to form part of the great peneplain of the Mississippi valley. The closely folded area appears to have been planed off in the same way as the broad flexures. Subsequent elevation of the

peneplained surface in a broad dome, higher in the south than in the north, set to work again the forces of degradation. In the south greater elevation, highly tilted strata, and soft beds alternating with hard, of the Coal Measures, gave rise to great contrasts of relief. In the north, with less height, gently inclined strata and resistant dolomites and limestones very different relief effects were produced.

The mountains of the Ouachita district appear to have tolerable even tops. In the novaculate region, in the extreme south, where the rocks are very hard, the mountains have only half the height of those a little farther north, but made up of softer beds, or soft layers alternating with harder ones. The great Arkansas River has cut its broad valley through soft shales of the Coal Measures. Everything goes to show that the present aspect of the whole elevated region is the result of one grand recent bowing up.

The correlations of the Coal Measures made by Dr. Drake are of great interest. In the June issue of this journal reasons were given for believing that nearly the whole of the enormous thickness of the Coal Measures of Arkansas was the equivalent of only the Lower Coal Measures of Missouri and Kansas — the Des Moines series. Dr. Drake's notes and map appear to afford conclusive proofs of this view. His great basal sandstone, "Lower Coal Measures," and the productive group (Cavaniol) taken together would appear to represent approximately the Des Moines series. I say approximately, for it is not yet quite certain just what is the upper limiting horizon of the "Cavaniol." On his map, where the western boundary of the latter leaves the territory northward, it meets the lower member of the Bethany limestone — the basal stratum of the Missourian series, and Upper Coal Measures of the western interior coal basin. The presence of marked escarpments at various places beyond this western boundary line are also taken as indications of the southern extension of the Kansas Missourian.

In like manner the Poteau group seems to be the equivalent of that part of the Missourian series of Kansas, below the Wabaunsee shales. Possibly its upper limiting horizon is even lower.

We are certainly deeply indebted to Dr. Branner and his associates for a set of contributions of much more than passing general interest and of inestimable local value.

C. R. Keyes.

The Newark System or Red Sandstone Belt (of New Jersey). By HENRY B. KÜMMEL. Annual Report of the State Geologist of New Jersey for 1897, pp. 25–159. Trenton, N. J.

In the corresponding report for 1896 Dr. Kümmel presented a brief report on the Newark system of the western part of New Jersey. He has now extended his work so as to cover the whole of the area of the system within the state, and the present report embodies the results of his fuller studies. As indicated in an earlier number of this JOURNAL, Dr. Kümmel finds the Newark system divisible into three series, the basis for subdivision being lithological, not palæontological. These divisions, commencing below, are (1) the Stockton series, the characteristic beds of which are arkose sandstones and conglomerates; (2) the Lockatong series, the characteristic beds of which are black shales, dark, massive argillites, and gray and green flagstones; and (3) the Brunswick series, consisting primarily of red shale and sandstone. Maps are presented showing the distribution of these several divisions. As a result of the profound faults affecting the western part of the system, the several series do not appear at the surface in single, continuous belts, but are repeated. The disposition of the outcrops is still further complicated by the folding which the beds of the system have suffered. In the eastern part of the state the Lockatong series does not appear, but the Stockton series is found in limited areas on both sides of the Palisade ridge.

One of the interesting facies of the system is the conglomerate which occurs along its northwest border, at and near its junction with the pre-Mesozoic terranes. This conglomeratic phase of the system assumes different aspects at different points. It is now made up chiefly of limestone, now of gneiss; and now of quartzite; but the significant point in the relations of these several phases of conglomerate is the fact that the larger areas of calcareous and quartzite conglomerates do not abut against older formations of limestone and quartzite, but against gneiss instead. The conglomerates are clearly shore deposits, and it is therefore inferred that the conglomerate beds were not derived chiefly from the older formations against which they now lie. It is believed that faulting along the contact of the Triassic system with the older formations is responsible for the lack of correspondence between most of the conglomerates and the formations against which they abut.

Another point of interest and significance is found in the fact that the conglomerates do not occupy a distinct horizon, but that each of the three series in turn becomes conglomeratic as the border of the system is approached. Incidentally it may be inferred that the northwestern extension of the system was never much greater than now, since the shore phase of each series is represented along the present border.

The relations of the igneous rocks of the system also receive much more systematic discussion than in any previous publication. Several small areas of igneous rocks (dikes) heretofore unmapped have been located. While the previous conclusions as to the intrusive character of some of the trap sheets and the extrusive character of others are confirmed, the evidence on which these conclusions rest is so fully detailed, and is in itself so decisive, that further discussion of this point is not likely to arise.

Many of the principal structural features of the Newark system have long been known, but no previous student of these formations has worked out the details of the structure with anything like the fullness shown by the present report. The general monoclinal structure of the system (strike N. 30° to 50° E, and dip 13° or 15° to the northwest) is found to be affected by several broad, gentle flexures, and by a few sharply marked folds, especially in the vicinity of the intrusive sheets of trap and along the greater fault lines. The positions of these flexures are given and their effects on the topography, where beds of unequal resistance outcrop, are pointed out. Even among the gentle folds of the system the axes of flexure sometimes depart from horizontality because of still gentler cross-folds, showing that the forces which deformed the beds were not confined to one direction.

The beds of the Triassic system have long been known to be faulted, but not until now have these faults been worked out in detail. Of the two major faults, one (the Flemington fault) was known before Dr. Kümmel's studies began, while the other (the Hopewell fault) was discovered by him. Both these faults have a throw of several thousand feet, and each causes the repetition of the outcrop of each of the three series of the system. Besides these two principal faults, displacements are believed to exist along the northwest border of the system at more than one point.

Of minor faults there are many. Something like fifty are described, and many figures are given showing in a graphic way the evidence on

which their existence is known. The throw of these minor faults varies from a few feet to several hundred. The faults enumerated are more frequent in the trap than in the shale and sandstone. Since faults are much more easily detected where they affect the trap, owing to the fact that this formation has come to assume the form of ridges since the faulting, it is inferred that minor faults affecting the more homogeneous portions of the sedimentary part of the system may have escaped observation.

But for the faults, the determination of the thickness of the system would be an easy matter. Allowance can be made for the faults which are known, but there is no way of taking quantitative account of those which have not been discovered. Impressed with the fact that there may be many undiscovered faults of slight extent in the homogeneous shales and sandstones, Dr. Kümmel has revised his estimate of the thickness of the system, and now gives the following figures:

Brunswick series, - - - - -	6,000 to 8,000
Lockatong series, - - - -	3,500 to 3,600
Stockton series, - - - - -	2,300 to 3,100
	11,800 to 14,700

The thicknesses of the principal sheets of trap are also given, the thickest being less than one thousand feet. A brief discussion of the conditions of the origin of the system is followed by a résumé of its economic resources.

The report, as a whole, presents in excellent form the results of a piece of work which is not likely to need revision. It is a matter of congratulation that Dr. Kümmel has this year been able to extend his studies over the Triassic area of New York.

R. D. S.

The Geological History of the Isthmus of Panama and Portions of Costa Rica. By ROBERT T. HILL, Bulletin of the Museum of Comparative Zoölogy at Harvard College, Vol. XXVIII, No. 5, pp. 151–285. Nineteen plates. Cambridge, 1898.

The results embodied in this report are based on a reconnaissance made by the author for Alexander Agassiz in 1895. In spite of the fact that the region concerned was only reconnoitered, the report adds

much to our knowledge of tropical America. Some of the geographic features which characterize the region have been briefly described by the author in earlier publications, but the geological results of the reconnaissance have not before been published. So far as practicable, Mr. Hill's conclusions are stated in his own words.

In the first place, emphasis is laid upon the independence of the North American, Central American, and South American orogenic systems. The Cordilleran system of North America ends in Mexico, a little south of its capital city. The Andean system of South America has its northern terminus east of the Isthmus of Panama, and has no genetic connection with the mountain ranges of the north coast of South America. If the Cordilleran and Andean systems were extended southward and northward respectively, they would pass each other in parallel lines hundreds of miles apart. The extension of the Andean system would lie not only east of the Cordilleran, but even east of the Appalachians, while the extension of the Cordilleran system would lie in the Pacific, far west of the South American coast.

Between the termini of these orogenic systems, with a trend at right angles to both, lies a third system, called the Antillean. It is this system of mountains which has determined the major topographic features of the Antillean region. The system includes the east-west ranges of the north coast of South America, those of the Isthmus, Central America, southern Mexico, and the Great Antilles. In the Caribbean sea, two east-west submarine ridges, separated by the Bartlett Deep, show that the east-west trend of the crustal corrugations of this region affect the sea bottom as well as the land. Like the greater systems to the north and south, the Antillean system is composed of folded sedimentary rocks, plus volcanic intrusions and ejecta. While each of the major orogenic systems dominates a continental area, the Antillean system "constitutes a mountainous perimeter surrounding the depressed basin of the Caribbean."

The primary geographic features of that part of the continent dominated by the east-west system are 1°, a volcanic plateau near the Pacific coast along the western termini of the ranges of the Antillean system, and 2°, the lower but mountainous area facing the Caribbean, consisting of folded beds of sedimentary rock, associated with igneous. To the north, the western termini of the Antillean ranges are buried by the volcanic rocks, but on the Pacific side of Panama, the Antillean ranges continue across the land area.

The surface of Panama is described as consisting of irregularly rounded mountains and hills, 200 to 1500 feet in height. Their topographic expression is uniform whatever the rock of which they are composed. Lack of systematic arrangement in their distribution is said to be one of their striking features, though an east-west trend is locally observable. Their form and arrangement are ascribed primarily to erosion.

"In common with the whole Central American region south of Yucatan, the Isthmus of Panama presents no such feature as a well-defined coastal plain like that bordering the eastern and southern margin of the United States. . . . . Such occasional levels as may be recognized on either coast are the products of the erosion of the greatly distorted sedimentaries and volcanic rocks. . . . . The Caribbean coast is generally marked by jagged and abrupt bluffs where the sea beats directly against the hills. The indentations are slight and far apart. The same may be said of the Pacific side."

The drainage of the Isthmus is defined as "ancient, mature and autogenous, consisting of deeply incised headwater ramifications drowned in their lower courses toward the sea." Although the drainage of the Isthmus is about equally divided between the two oceans, there is no well defined watershed separating the waters flowing into the Atlantic from those flowing into the Pacific.

The Isthmian region is now undergoing rapid erosion, the result of the excessive rainfall (154 inches in 1894), and of the activity of the waves of the oceans. The topography of the sea bottom on either side points to a former greater expansion of land, and therefore to the fact that the narrow neck of land is, and has been disappearing under the influence of the agencies mentioned. This conclusion is further borne out by the outlying islands, which, by their structure and relations, show themselves to be isolated remnants of the mainland.

Two detailed geological sections are given, one across the Isthmus from Colon to Panama, and the other across Costa Rica. In the Isthmian section, seven structural units are recognized. These are (1) the fringing coral reefs; (2) the coastal swamps of both coasts—elevated plains of sedimentation; (3) the Monkey Hill and Panama benches—elevated base-leveled plains; (4) the folded and disturbed Tertiaries which owe their positions to the series of post-Tertiary (post-Oligocene) orogenic foldings along the Caribbean side of a more ancient nucleal region; (5) the numerous protrusions of basic igneous rocks,

the age of which is not definitely known; (6) the sedimentary rhyolitic and andesitic tuffs, the Panama formation, older than the basic igneous formations; and (7) the granitic rocks, the oldest of the region. The sedimentary rocks of the section fall into three categories: (1) those of supposedly pre-Eocene age, occurring on both sides of the Isthmus; (2) the fossiliferous Tertiary beds of the Caribbean side, and (3) the Pleistocene beds deposited synchronously on both sides.

The rocks of the first of these three classes are so distorted and concealed by later igneous protrusions and deposits that little was learned of their relations. They are composed almost entirely of rhyolitic and andesitic material. The beds of the second class are referable, on the basis of their fossils, to the Eocene and Oligocene, corresponding approximately with the Tejon, Claiborne and Vicksburg formations of the United States. They are composed mainly of muddy sediments with more or less sand, glauconite and lignite. Limestone occurs at two horizons. It is to be specially noted that the Tertiary deposits of the Isthmian section end with the Oligocene (early Miocene), and there is nothing to indicate that sedimentation was in progress in the Isthmian region during the later Miocene and Pliocene epochs. The inference is that "the Isthmian land was of much larger area during these later epochs than in Eocene time or at present." The thickness of the Tertiary system is thought to be as much as 1000 feet, and possibly much more.

The igneous rocks of the Isthmian section consist of (1) granite in ranges having an east-west trend; (2) rhyolitic tuffs and pumice, igneous in origin, but sedimentary in arrangement; and (3) basic igneous rocks, occurring as intrusives, eruptives, tuffs, etc. The basic rocks are younger than the others, but are thought to have been in existence during the deposition of the later Eocene sediments. Other considerations prevent the reference of these rocks to an earlier period, and lead to the conclusion "that the most marked volcanic episode of the Isthmian region took place during the later Eocene epoch." It is thought that there are also late Tertiary syenitic intrusives, which "now form the core of great mountainous protuberances."

Throughout the Isthmian region, the surface red clays conceal all the formations. They are believed to be largely the residuum of rock decay. The extent of this decay is said to be "enormous, extending often to a depth of over 100, and seldom less than fifty feet."

In the Costa Rican sections the principal geological features may

likewise be grouped in seven categories. There are (1) the foundation rocks of ancient quartzites, serpentines, jadeite, and granite, probably pre-Cretaceous; (2) limestones, which are believed to be Cretaceous; (3) basic igneous rocks of Eocene, and possibly of late Miocene age; these rocks conceal most of the older formations and are, in turn, largely buried beneath later volcanics; (4) the marine Tertiary sediments, Eocene to Pliocene inclusive, of the Caribbean side; the early beds of this group are extensively disturbed, elevated and broken through by igneous protrusions; against these deformed and eroded strata the Pliocene beds rest unconformably; (5) a line of volcanoes surmounting the Sierras; (6) the Pleistocene sediments of the coasts, and (7) the "bolsons," base-leveled plains, benches, canyons and other topographic features.

In this section the "bowlder clays" of tropical America are encountered. The study of some of the craters of the region throws some light on the origin of these clays. From the craters fine material, such as scoriaceous ash, is thrown in quantity. With these fine products are also many large bowlders of black, massive igneous rock. Subjected to prolonged decay, this mixture of fine and coarse materials would, it is affirmed, leave a residuum identical in appearance with the bowlder clays. The glacial hypothesis, as an explanation of this formation, is regarded as untenable.

On the slopes of one of the mountains, Irazu, between the altitudes of 7000 and 9500 feet, there is found a fine pulverulent yellow dust, which is "in every way identical in lithological appearance and behavior with the loess deposits . . . . of the Missouri and Ohio." This formation is composed of the minerals common to the lavas of the region, but its mode of accumulation is not discussed.

Comparing the two sections, it is stated that "the Panama section is across an old land now nearly graded to the sea, where vulcanism has been quiescent since the Tertiary time," while "the Costa Rican section presents us a view of an ever-growing land where volcanoes have continued to pile their débris from Cretaceous time to the present."

Under the caption, "The Union of the Continents and the Problems of the Straits," the general relations of the Central American and Isthmian regions are discussed. The meager knowledge at hand indicates that "previous to the vast accumulations of more modern igneous and sedimentary rocks of Tertiary and post-Tertiary age, a foundation of granitic rocks, occurring in east and west arrangement,

existed in the South Isthmian and Central American region, extending in echelon arrangement from the longitude of Trinidad through forty degrees to near that of Acapulco, Mexico, directly across the path of the main continental trends." Palæozoic rocks are known with certainty, in the general area under consideration, in but one region, viz., in the Republic of Guatemala, and the adjacent Mexican border region. Their surface development is certainly very meager south of the United States. Triassic rocks, likewise meager south of the United States, also occur in Guatemala, but Jurassic beds are not known at any point in Central America. Cretaceous strata are much more widely distributed in tropical America; but while they cover most of Mexico, it is doubtful if the two oceans were at any time connected across this country in the Cretaceous period. This conclusion is based on palæontological evidence.

As to the Tertiary beds, the facts now in hand "indicate the existence of a continuous littoral of older Tertiary sediments around the Caribbean side of the tropical American region, and incidentally a preëxisting land which they bordered. . . . . These older Tertiary beds . . . . probably belong to the continuous series of sediments of the Eocene and Oligocene epochs. . . . . The Pliocene formations have not been clearly distinguished . . . . from the Pleistocene. There is an intermittent fringe of alleged Pliocene deposits around the Caribbean coast, unconformably deposited against the older continental mass. . . . . We may infer from the relatively slight area of the marginal development of rocks of this period, and their absence in the elevated or folded regions away from or much above the coast line, that it was just prior to the Pliocene period or during its earlier days that the Caribbean coast line, as a result of the tremendous orogenic processes by which the earlier Tertiary rocks were deformed, practically assumed the slope as we now know it."

In elaboration of this point, it is further stated that the early Tertiary strata have "since their deposition been elevated above the sea to great heights by folding on the Caribbean side of the old Isthmian protaxis until they stand 3000 feet in Guatemala, 5000 in Talamanca, 300 near Colon, and 500 at Cartagena. . . . . In Hayti, Cuba, and Jamaica, these plicated, Cretaceous, and early Tertiary rocks are found at altitudes exceeding 10,300, 8000, and 7250 feet, respectively, above the ocean. The east and west strike both of the Tertiaries and of the basic igneous rocks along the northernmost coast of South America

and in the Great Antilles is directly in harmony with the east and west trend of the same phenomena upon the mainland, and we cannot escape the conclusion that they are the product of the same great orogenic revolution, the age of which was mid-Tertiary, for rocks of early and late Eocene (and Oligocene) age everywhere, as exposed along the Caribbean coast, and in the Great Antilles, are folded by these mountain-making processes, while the Pliocene and Pleistocene are more horizontally laid down against the seaward margin of the mountain masses."

It is worth noting that the great orogenic movements of this region, dating from the later part of the Miocene, are in harmony with the great disturbances which took place in several continents at about the same time. They furnish a significant commentary on the infelicity of the current grouping of the Miocene and Pliocene under the common name Neocene. Nearly everywhere outside the regions of glaciation, the Pliocene and Pleistocene are more closely associated than the Miocene and Pliocene. The above use of the term Neocene makes this *period name* cover an interval of time in the midst of which occurred one of the most profound physical revolutions to which the earth's crust has been subject. For such use of the term there is but one analogy in the nomenclature of post-Algonkian time, namely, that of the use of the term Silurian, to cover all beds between the Cambrian and Devonian, although in the midst of this division occurs the greatest break, both stratigraphic and palæontologic, in the whole Palæozoic. The other physical revolutions comparable to that which took place at the close of the Miocene mark not simply the close of periods, but of eras.

In post-Miocene time, or perhaps accompanying the orogenic movements referred to, there was epeirogenic uplift and erosion, followed by moderate subsidence, and still later by uplift of slight extent, converting the shallow margin of the sea into low-lying coast lands.

The igneous rocks of the region appear to have a wide range in age. The age of the granitic mountains of east-west trend is not known, but they seem to be mainly pre-Tertiary, and probably pre-Cretaceous. Some of them may be much older. The later igneous rocks of the region seem to date in part from the later part of the Cretaceous period. Here belong the rhyolitic tuffs of the Panama formation which is believed to be pre-Tertiary. In the early Tertiary also there was great volcanic activity, but whether the vulcanism of the

close of the Cretaceous, with its accompanying disfiguration of topography, "was continuous to the present, or alternated with long periods of quiescence, cannot be answered." Thus volcanic activity accompanied the orogenic movements of Miocene time, giving "the most cataclysmic revolution of all geologic time and place."

Summarizing the evidence touching the union of the northern and southern continents, it is said that nothing is known of their relations in the Palæozoic; that land may have been continuous between them in the early Mesozoic; that it was probably so in the Cretaceous; and that in the Tertiary period only, in later geologic time, does the connection of the oceans across tropical America seem to have been possible. For their connection, even in this period, the evidence is much less conclusive than is commonly believed. For such connection "no stratigraphic proof has been discovered," and the physical character of the Tertiary sediments seems to be distinctly against any broad union. The only evidence pointing to their connections is palæontological, and even this is meager. In a single terrane of the Eocene, five species of mollusks on the Caribbean side of the Isthmus occur also in the Tejon Eocene of California. These species are held to indicate that in the Tejon epoch there was at least a shallow communication between the oceans, and that "to this epoch alone can the date of an interoceanic connection be assigned by direct palæontological evidence. . . . . All the authentic biologic and geologic evidences are entirely opposed to the possibility of a communication between the two oceans across the Isthmus or tropical American region in Pliocene or Pleistocene time." The statement of Upham, Spencer, and others, that marine Pleistocene fossils have been found at great heights on the Isthmus, is said to be erroneous.

R. D. S.

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THE

JOURNAL OF GEOLOGY

OCTOBER–NOVEMBER, 1898

THE CLASSIFICATION OF STRATIFIED ROCKS.

THE problem opened for discussion in the "Symposium on Classification, etc," in the May–June number of the JOURNAL OF GEOLOGY is much wider than the compass of the particular questions raised. It was by no means lack of interest in this problem, or in the particular questions, that led the writer to refrain from participation in the symposium. My opinion, then as now, was that the real difficulties in the case will not be solved by reaching even uniform replies to the questions; and further, the meeting which was held in September, of the International Commission on Stratigraphic Classification, which I then expected to attend, was another reason for delay in expressing an opinion till after the meeting of the commission.

Taking up the subject, where it was opened in the "Symposium," I will attempt first to give a reply to the preliminary question, raised in the introduction by the following sentence, viz.:

"Granting that these questions cannot be answered finally at present, or in the near future, it is still urgent to inquire: *By the use of what system, provisionally adopted for current use, can we best work on toward better systems in the future?*"[1] In framing a reply to this question, let me first call your attention to the steps already taken toward the construction of a provisional system of general classification and nomenclature for stratified rocks.

It will be remembered that in 1878, twenty years ago, the

[1] JOUR. GEOL. Vol. VI, p. 334.

first International Congress of Geologists met in Paris. The chief purpose of this congress, as set forth in the first article of its programme was, "*Le'unification des travaux géologique au point de vue de la nomenclature et du figure*," which in English is—the attainment of uniformity in the naming, classifying and mapping of geological facts. At Paris papers were read and discussions were held, but few results were reached beyond the appointment of commissions to prepare for definite future work. At the second meeting, held in Bologna in 1881, a commission was appointed with power delegated to take the necessary steps for the making of a geological map of Europe. The discussions at this congress and at the next, held in Berlin in the year 1885, and the work of the commissions meeting at Foix in 1882, at Zurich in 1883, at Geneva in 1886 and at Manchester in 1887, all were directed toward the perfecting of a system of nomenclature, classification and cartography upon which to construct this European map. The map necessarily covered the territory of a number of independent states, whose geological surveys had been carried on independently by men speaking in several different tongues, and it was necessary to reach uniformity in nomenclature and method of representation of the facts for all these European states, in order to construct that map. Although the map was not then complete, at the time of meeting of the London Congress in 1888, the great majority of the disputed questions had been settled. In many cases the agreements were rather compromises, necessitated for the execution of a common map, than real settlement of the disputed points, or the attainment of actual uniformity in usage.

Thus the European classification and nomenclature, as set forth in the decisions of the congresses previous, it may be said, to St. Petersburg, were incident to the preparations of a geological map of Europe, and should not be regarded as constituting a universal scheme, any more than that devised for the preparation of a geological map for a similarly restricted area in another continent. Some American geologists realized this fact and, while taking deep interest in the discussions and the

expression of the views of their fellow workers, saw no reason for interference with, or the taking of an active part in, the solution of questions which pertained so largely to European geology. It was evident, to one watching the work of the congress, that the difficulties and dissent increased as the territory under consideration enlarged. England and Russia whose domains lay farthest from the center of Europe had greater difficulty in adjusting their classifications and nomenclatures to the common scheme than did the diverse states situated in the central part of Europe; and the geologists of the United States, most of all, have found insurmountable difficulties to the complete application of the European scheme to their own work. After the questions relative to the construction of the geological map of Europe were settled, this general dissatisfaction with attempts to settle questions of science by majorities resulted, at the London meeting, in the decision no longer to settle questions of general debate by formal votes; and in the following congresses, at Washington, Zurich and St. Petersburg, only such questions as had been submitted for consideration to commissions, and were carefully formulated, were put to formal vote of the body of the congress.

While these things were going on in the congress, the geologists of the United States were active along the same lines in their own country.

A few American geologists attended the Berlin Congress in 1885, and prepared a detailed English report of the proceedings. (The official proceedings of the congresses have been reported in French.) After their return an American committee, composed of fifteen geologists, set to work to prepare a report on the classification and nomenclature then in use in America. This report was submitted at, and published as a part of the proceedings of, the London Congress in 1888. In this report, the state of progress toward uniformity in the United States, of both nomenclature and classification of stratified rocks was given in summary form; and some of the difficulties and diversities in usage were pointed out. Following this, and probably suggested by one of

the chapters of the report, a Division on Correlation, as a distinct department of the survey, was organized by the Director of the United States Geological Survey. A series of bulletins were published (Nos. 80–86), in which a thorough discussion was made of the historical development of knowledge, nomenclature, and classification of each of the grand systems of the geological column on the American continent. The first "essay" was published at the time of the Washington Congress, in 1891. Two of the volumes contemplated have not been published at the present date. Each of them was prepared by a specialist and was based upon thorough study of literature and knowledge of the facts.

In this series of essays, the fact was clearly demonstrated, (which had been already announced for the Devonian in the American committee's report) that the formations of each one of the grand geological systems present such great diversity in physical features and even in the particular composition of their faunas, that two, three, and, in some cases, four distinct classifications, with as many sets of different names are needed to represent the true state of facts regarding each one as known to science at the present time, in the United States alone.

The first of this series of bulletins on correlation was issued in 1891, at the time of the meeting of the International Congress of Geologists at Washington.

While the European geologists were struggling with the various difficulties arising in the attempt to put the geological features of the various states of Europe onto a single map, with a single system of color conventions and a common legend, the United States Geological Survey was dealing with similar problems on the continent of North America. Not only was the territory covered by the work of the United States Geological Survey quite as vast as that covered by the map of Europe (the total area of Europe being 3,800,000, and that of the United States being 3,536,290), but the geology in the several states in America is found to present a greater variety of expression and more complete diversity of composition than is expressed in the states

of Europe altogether. So that the members of the United States Geological Survey, in their own legitimate work, have been obliged to consider as wide problems as have engaged the International Congress of Geologists, whose preponderating majority is made up of European members.

As early as 1881 a cartographic system was devised by the survey for the preparation of its maps. This was described in the second annual report of the survey and also was communicated to the Second International Congress meeting at Bologna in 1881. As happened to similar schemes presented by representatives of the various Europeans, this was a provisional scheme whose modification was the natural result of their comparison at the meetings of the congress, and the trials of the system in actual mapping of widely diverse problems.

In the years 1889–90 the importance of a uniform and established scheme for all the maps of the United States led to the holding of a "Conference on Map Publication," which was called by the Director of the Survey, was composed of nineteen of the most experienced and ablest geologists of the country, and was held in Washington, in January 1889,

As a result of this conference a scheme of classification and set of rules for use in mapping the results of the work of the United States Geological Survey were prepared. These rules were published in the Tenth Annual Report in 1889, and have been the basis upon which the reports and maps of the survey have been constructed since then. The scheme differs from the European scheme adopted by the International Congress in many particulars. The difference which is most striking on comparing the two, has relation to the principle of uniformity itself. The European system is built on the assumption that uniformity in nomenclature is practicable, and should be attained as far as consistent with the divergent opinions and practices of the various states concerned. The United States system is fundamentally elastic, and rests on the general assumption that uniformity is practicable only in respect to the grander divisions, and that diversity in both naming and classifying the subdivisions of

the geological systems is both practicable and necessary to the true representation of the facts in the case.

It is this fundamental characteristic of the United States scheme which furnishes the answer to the question quoted at the beginning of this article from the "Symposium" of a few months ago. The system which should be adopted provisionally for current use, both by geological workers and by teachers, must recognize this fundamental fact, that the units which it is attempted to name and classify in stratigraphical geology, are not constant units, presenting uniform characters for the whole world or for each continent, but are very inconstant, preserving the same characters for only very limited areas.

Since this is known to be the actual fact regarding geological formation, it is useless to attempt to hold to a rigid system of nomenclature, or to raise the vain hope that the use of the same names will help us over the difficulties arising from the great diversity of facts.

Having recently attended the meeting of the International "*Commission des classifications stratigraphiques*" in Berlin, it is with great pleasure that I am able to report that the commission appointed at the St. Petersburg Congress adopts this principle of elasticity in all matters of detail as a foundation principle in the construction of rules for use in discussing international stratgraphy. Professor Renevier, the chairman of the commission, has not yet published his official report of the proceedings, hence I will not attempt the discussion of details until the report is received. But I believe it will interest all American geologists to know, that several principles, which we believe in, and on account of which has arisen some of our dissatisfaction with the European nomenclature and classification adopted by the International Congress for the map of Europe, will be recommended as the basis of an international system of classification.

One of these points is the recognition that the so-called systems, or units of the second order, are the smallest divisions of the geological scale to which uniform names and position in the classification can be given in an international scheme.

A second point is that, even in the definition of these systems, a degree of elasticity must be left for the geologists of different continents and countries.

A third point is the adoption of a set of prefixes (*Paleo*, *Meso* and *Neo*) to be attached to the name of the system as a method of reaching comparative uniformity in the naming of divisions of the third order.

The fourth point is the leaving to the local geologist, the task of selecting local geographic names for the divisions of the fourth order.

Other points were discussed, but these are sufficient to show the trend of the discussions.

When the report of the commission is published, a fuller presentation of the matter will naturally occur, but until then it seems to the writer that any attempt to make a more rigid classification or nomenclature for general purposes is not to be desired.

What we all are striving for is a scheme of nomenclature and classification by which we can clearly express and represent the grander conclusions of our science which are at present so much hidden by the multitude of details. But it is necessary to bear in mind, while seeking to attain this end, that refinement or uniformity in classification, or in methods of representing the facts, will not discover the principles coördinating and determining the relations of these facts to each other. The system of our classification must be based upon the knowledge already possessed, and so long as we have not discovered the clue to the great diversity presented by stratigraphic units, we must retain all the diversity they express in our detailed descriptions of them, and wait for uniformity in respect to the lesser matters until we discover the principles upon which the diverse phenomena are bound together into a systematic whole.

It must be realized that many of these diversities, in name and relations to each other of the facts of geology, which confuse the student as his studies extend to details of the geology of other areas and other countries, are not due to different usage,

language, or understanding, but to actual diversity in the facts themselves, which only wide and profound studies in comparative historical geology can reduce to a system. When, therefore, we attempt to speak of geological events in their chronological relations, the known truth can be expressed only by an elastic use of a universal scale whose divisions are few, and whose boundaries are not precise.

HENRY SHALER WILLIAMS

NEW HAVEN, CONN.
October 28, 1898.

THE SO-CALLED CRETACEOUS DEPOSITS IN SOUTH-EASTERN MINNESOTA.

THE extent of Cretaceous formations in Minnesota has not yet been exactly determined. Small areas of the Cretaceous are known to be extant in several places and also large areas are believed to lie hidden under the drift in the western half of the state, adjacent to or continuous with the Cretaceous formations which occur in North and South Dakota and Iowa. In the region where large extent of Cretaceous is thought to exist in Minnesota, the glacial drift is very deep and the underlying formations are little, or not at all, accessible. In other regions where there is generally less drift, there is not much Cretaceous deposit. A few isolated areas only are reported to be Cretaceous-covered and these alone attest whether or not the Cretaceous deposits to the westward of Minnesota had once extended quite continuously eastward in the state to or beyond the central portions, as some geologists have thought. As far as has been ascertained, all known outcrops might well belong to local or even inland deposits. Again, whatever its extent, the Cretaceous now lies, when present, always immediately beneath the glacial drift and in this position it might presumably be found. strongly eroded, and, therefore, we not only do not know the original extent of Cretaceous sedimentary deposits in Minnesota but also we cannot safely predict how much of that unknown quantity might now be extant.

The known extent of the Cretaceous in Minnesota is very small, while the sometimes estimated extent is very large. This statement may be well illustrated by reference to the final reports of the Minnesota Geological Survey, in which the maps of the several counties in volumes one and two, represent a few scattered spots of known Cretaceous, while the map of the state, in volume three, which is constructed from the same data

shows one-half the area to be probably Cretaceous, beneath the drift. Further geological investigation must of course tend to lessen this enormous difference between the known and the possible Cretaceous. During the last two summers I have had opportunity to investigate the supposed Cretaceous in southeastern Minnesota with the surprising result that the reported areas and deposits, in some instances prove to be doubtful.

In this region, there have been mapped, as mentioned, probable Cretaceous areas, covering a small spot in Goodhue county, patches in Fillmore county, and a continuous area in Steele, Dodge, Mower, Freeborn, Faribault, Blue Earth, Brown and other counties. The reported known areas are that of Goodhue county, some clays in Mower county, near Austin, and gravels near Hamilton, small pockets of clay in Blue Earth and Scott counties and certain strata in Brown and Nicollet counties.

The last named is very probably Cretaceous. Near New Ulm, Brown county, have been found fossil leaves which are described by Leo Lesqueseaux[1] and referred by him to the Dakota group. I have visited the same locality and collected some of these fossils, which are abundant only in a thin discontinuous stratum of fine sandstone. The whole bed, consisting of coarse sand with some irregularly distributed clay is 30 feet or more thick and rests upon a rotted granitoid rock, which rises 10 feet above the level of the Cottonwood River. The fossil leaves were found a few feet only above the sandstone's base, in a layer which has a concretionary-like surface, and except for its width of several feet might be called a pebble, which other smaller fossil-bearing concretionary masses in the same zone certainly appear to have been. The leaves are found therefore in a broken stratum, which, however, was, with little doubt, contemporaneously deposited and broken, so that the contained flora is indicative of the formation's age. The materials of the sandstone are imperfectly assserted and again almost arcose in character.

Other sand and clay exposures of the same age have been des-

[1] Minn. Geol. Surv., Vol. III.

cribed from the neighborhood of New Ulm on the Minnesota River, but since they have afforded no further conclusive evidence, and since they too lie on the border or outside of what should be called southeastern Minnesota, I pass them by. Again, the supposed Cretaceous, which occurs farther down the Minnesota River valley at and below Mankato, might be passed perhaps justly with a denial that it is Cretaceous. Of course Cretaceous materials and fossils may be found in drift there and elsewhere in the state. But the beds of fine clay, containing some sand, which are on and in the Shakopee and Oneota dolomite formations, bear no fossils. They are like mere pockets of residuary clays from limestones and dolomites. They occur as white or variegated clays in the seams or in pockets or resting irregularly upon the iron-stained surfaces of the dolomites. Gravels of later age, possibly from early glacial drift, have been also described as Cretaceous, while others are possibly early Pleistocene, possibly Cretaceous. There is little or no conclusive evidence of the age of these small deposits. They need therefore no detailed description here, but a full account of them can be found in Final Report, Vol. I, p. 432; Vol. II, p. 127, Minnesota Geological Survey.

The reported Cretaceous at Austin, Mower county, is more important, because upon its character has depended the coloring of several counties on the geological map. Austin lies about 60 miles southeast of Mankato, 85 miles therefore in the same direction from New Ulm. The map coloring from Mankato to Austin depended upon the occurrence of supposed Cretaceous at Austin. Here occurs a variegated clay ranging in color from pea-green to bright red and yellow, resting upon a limestone or dolomite of Devonian age. It has not however been found in place, but is always, as far as known, involved in the glacial débris. Whatever the origin of this clay, it is now glacial drift, a Pleistocene deposit, and therefore not properly to be mapped as Cretaceous.

Regarding the question whether or not these clays were derived from Cretaceous formations, it must be said that the evi-

dence indicates strongly that they were not. For example, a large pit opened by the Austin Brick and Tile Works showed about ten feet of clay of all colors jammed together, bearing bowlders of granite, especially in the upper part, and large blocks of Devonian limestone, especially in the lower part. There is no mistaking the blocks of limestone, for they pass gradually into that which underlies in heavy strata throughout this region. The limestone blocks are blue or buff like the Devonian strata in color, though, locally, they are found in every degree of decomposition, so that in one place a complete series from fresh rock to iron concretion and red clay can be gathered. At Varco, below Austin, in quarries of the Austin Cement Works, a preglacial channel about ten feet deep in the Devonian limestone is well shown, and in it the rock surface is black stained and decomposed. Upon this surface is a somewhat disturbed, variegated clay, not in strata but coating the inclined surface. Reconstructed, the preglacial condition around Austin seems to have been simply that the Devonian limestone, blue in original color, passed upwards into buff of the same formation. This, twenty feet or more thick, was penetrated by clay-filled cracks at the top, or covered by a coating of black iron-manganese oxide, etc., from one to two inches thick; the former condition passing to a red clay with black concretions and decomposing brownish limestone blocks; the other phase, that of the black unbroken rock surface, as at Varco, passing simply into homogeneous residuary clay. The pea-green clay is calcareous and it was not residuary but formed strata or laminæ between the limestones. Such a clay is seen in the Devonian at Le Roy, in the southeastern part of the county,[1] and again it should not be forgotten that the Devonian at Austin extends upwards nearly to the horizon of the Rockford shales, so well developed southward in Iowa.

The identification of the clays at Austin as Cretaceous was based upon a few specimens of fossil leaves found in digging a well (*vide op. cit.* p. 354). At first the subjacent limestone was also called Cretaceous by N. H. Winchell, but this mistake was

[1] See also Geol. Surv. Minn., Vol. I, p. 357, l. 7.

soon corrected through the identification of fossils by H. S. Williams. The occurrence of a true Cretaceous fossil in this Pleistocene deposit does not prove the origin of the clays, because also pre-Cambrian rocks and Devonian fossils are scattered quite abundantly in it. The Austin clays are not Cretaceous and it is very doubtful that they ever could have been such.

Another supposed Cretaceous deposit has been described, also by N. H. Winchell in the northeastern part of Mower county. There is, in this district, a "white pebbly conglomerate which passes into a ferruginous grit." In the adjacent part of Fillmore county, the same occurs, and was identified as Cretaceous. Near Spring Valley, a few miles farther south, a blue clay is said to represent the Cretaceous. No actual outcrops were known of strata *in situ*, and one might not now refer any of these to the Cretaceous, especially since the "Austin rock" is now known to belong to a different formation. Indeed, they were so referred only with doubt by Professor Winchell. Of course, Cretaceous as well as Devonian, Ordovician, Cambrian and older rock débris might be found commingled in the Pleistocene drift.

In Goodhue county, about sixty miles northward from Austin and ninety east of New Ulm, there is another deposit consisting of interstratified clay and sand, which is described by N. H. Winchell as Cretaceous.[1] Fossil leaves have been found in the sandstone and are identified by Leo Lesquereaux as Cretaceous fossils.[2] I have verified the occurrence of the leaf imprints, though of course their identification is not questioned. The fossils belong to the same age as the strata and the latter are therefore of Cretaceous origin since the former are.

Before describing this patch of sand and clay, it may be recalled that the deposit lies beyond the limits of Wisconsin and Iowan drift in the region of loess and Kansan or pre-Kansan drift. It is in an undulating prairie bordering on the deep valleys which lead to the Mississippi valley about twelve miles

[1] Op. cit., Vol. II, p. 43.

[2] They are described in Final Rep., Vol. III, Minn. Geol. Surv.

distant toward the northeast. The Cretaceous lies on one of the higher hills of the prairie. It is covered by the loess five to ten feet thick, which also covers the Kansan eskers, the Saint Peter sandstone of the butte-like hills and, at lower levels, the Shakopee dolomite hills, and then, on the steep sides of the valleys, the Oneota dolomite and Jordan sandstone. The glacial till or gravel is spread beneath the loess, over the same Cretaceous, Ordovician and Cambrian formations. Under this drift, the dolomite formations are commonly protected by a dark-colored residuary clay, containing chert and iron concretions. Two or three miles to the westward from the Cretaceous patch, the Saint Peter sandstone is conformably overlaid by the Galena (Trenton), and upon that may once have rested the Maquoketa (Hudson) strata. Now at the particular locality where the Cretaceous patch occurs, there is neither Galena nor Maquoketa extant, but the Cretaceous rests upon the Saint Peter sandstone or possibly in part upon the Shakopee dolomite. Further, it is evident, as shown by N. H. Winchell (*op. cit.*) and others, that all the geologic formations, from the Galena down to and below the Jordan sandstone, were once, in this region at least, uniform, coextensive, sedimentary deposits, and that all the valleys are due to later erosion. This valley cutting was accomplished before the glacial deposits were spread on them. The erosion of the loess and glacial till and gravels now going on is very slight as compared to that which produced the valleys over which those deposits have since been spread.

The Cretaceous strata lie where erosion had already obtained. The Galena series, at least, must have been eroded away before Cretaceous deposit could be laid upon Saint Peter sandstone. Again, the valleys on either side of this Cretaceous, as we now see it, must be younger than such a sedimentary formation if the same is *in situ*, else the formation should lie in the valley and not on a hill. This Cretaceous patch, like the hills of Saint Peter sandstone and of other older formations in the same locality, must be the outlier or eroded remnant of a once more extensive sedimentary deposit; unless, like the bowlders of

granite, the gravels and the till, it was transported by the glacier *en masse* from the northwest.

The Cretaceous in Goodhue county is known to cover about one-half square mile from 0 to 40 feet deep. It lies in sections 3 and 10, town of Goodhue, three miles northward from Goodhue village, and one and one-half miles east of Clay Bank station. It consists of a succession of sand and clay strata which are now quite irregular, although when deposited they could not have been so. The top of the mass always shows disturbance from a glacier which has moved over it, although comparatively lightly, from a northwesterly direction. In the many pits which form a long series of exposures, no stratum appeared undisturbed, but rather every one has been shifted on the other. "The thickness of the parts varies in short distances, some of the beds tapering to points and wholly disappearing."[1]

It should be emphasized, that the irregularities of the twenty or more successively alternating sand and clay strata, are not due to sedimentation as believed heretofore, but to later dislocation which was evidently glacial. In the most regular sequence observed, which is seen in a pit on the west side of the highway, every stratum has been shifted upon the other. In other exposures they show even more irregularities, and it is quite impracticable to describe all the peculiarities of this kind. But all of them are modifications of a once regular series of alternating clay and sand strata which, as is shown by their continuity in some cases, were probably very uniform and continuous when deposited as sediment. In one case a fairly regular succession now forms a syncline. The strata dip on the one side at an angle of fifteen degrees for forty feet at least. The other side is steeper and shorter. One coarse sandstone stratum in particular runs uniformly two feet thick down one side and up the other. It could not have been so deposited. A clay stratum on the contrary is bunched into a lenticular mass in the syncline. It would not have been so deposited. Rather frequently a sand stratum is interrupted or widely isolated in thick lenticular

[1] WINCHELL, op. cit., p. 44, l. 6.

masses, then included in the clay. An exceptional case of dislocation is seen in one corner of the easternmost exposure. Here a mass of sand, eight to ten feet wide and exposed ten feet deep, interrupts the strata. Its median portion, vertically, shows obscure horizontal stratification. On the right and left, clay only, joins irregularly on the sand in large confused masses, which project in an irregular sheet two feet thick, over the same. Probably the clay extends under it. The adjacent sand strata are cut off or squeezed out abruptly by the clay, which surrounds the large sand mass. In composition this sand horse is coarser than any of the strata, but near by the same kind of coarse sand was found scattered loosely over the top, like drift. It is not ordinary glacial sand however.

Lamination is generally obscure. The clay is without lime and is decidedly tough and fine in texture. The sandstones are either nearly white and friable, or have been converted to a veritable crystallized iron ore in parts of the same stratum. It is in the dark red hard parts of the sand strata that the fossil leaf imprints occur. These parts of the strata have resisted distortion, being only here and there brecciated, so that character of stratification, like the fossils, may be clearly discerned. The rock alterations must have preceded the mechanical disturbance of the strata. Small pieces of mica further characterize the sand and coarser clays of the strata.

Excepting in the case described above, the strata are not jammed together but appear rather to have slid one on another. Even the top in contact with the glacial drift is not mixed with pebbles or bowlders, although it has been distorted to the depth of one to three feet by the glacier. The till, two feet thick or merely a thin covering of gravel, with here and there a large bowlder perched up into the loess instead of buried in the Cretaceous clay, overlies the whole mass.

What lies beneath the Cretaceous here is unfortunately not known, except in the southern part of the field, where an excavation for the railway passes through the Saint Peter sandstone. The top of exposed Saint Peter rises as high as that of

the Cretaceous. It is crusted over in one place with a black coating of iron. Upon it is found a few inches of unassorted fine sand like that of the Saint Peter sandstone, and numerous small bright pebbles, while in other places the loess rests upon it instead. On either side of the Saint Peter sandstone are Cretaceous strata which are now weathered, however, and their relation to the Saint Peter is no longer clearly defined in the exposure. But they seem to have conformed to the surface of the latter, without intervening deposit. The generally undulating arrangement of the strata in all the pits argues also that they conform to an irregular or undulating surface beneath them.

If the strata had been deposited just where they now lie, they would have been unconformable to the underlying structure, and horizontal instead of inclined. The strata have been disturbed if not transported *en masse*. Whether they have been moved a few feet or a few hundred miles remains to be shown. Likewise, one must define the mass as either in its originally deposited character, Cretaceous, or as now glacial drift. An elaborate discussion on how far rock must be moved out of location before it is to be called drift, would end in this case, however, only in the recognition of the fact that possibly some unexposed stratum may be still *in situ* as Cretaceous.

I endeavored to find some proof that this patch is an outlier of a once widespreading formation of this region. The striking presence of mica sand argues a general formation rather than a local one. In Cretaceous time, the only known source of mica must have been either granitoid rocks far to the northeast or to the northwest, or possibly the Saint Lawrence formation and Cambrian sandstones, the exposures of which could have been only far distant, while Cretaceous sediments were depositing three hundred feet above them in this region of nearly horizontal formations. Moreover I did not find that the Saint Peter sandstone detritus forms any part of this Cretaceous rock. Yet, the Saint Peter stands adjacent and protrudes to the height of the other deposit. The materials are evidently from distant sources. In the vicinity of this particular hill are other hills or

buttes which must be equally high, because they cut off the view of the more distant horizon. On these hills are farmhouses, with the never-failing wells two hundred feet deep. Excavations for cellars have also been made, but although the value of the "Clay Bank" must inevitably have been impressed upon every mind in the neighborhood, still no one is known to have observed similar clays or equivalent deposits on other hills. It is very probable that they do not exist.

In view of this contradictory evidence, other hypotheses were sought which might harmonize them. It may be suggested that either the deposit was that of a meandering river, or that the mass has been borne hither by the capricious glacier. To the former hypothesis there is the seeming objection, that the alternating strata of uniform composition and sharply defined stratification, do not suggest a river flood deposit, but it may explain the presence of mica in the sand. To the other hypothesis, however, no objection arises which cannot be circumvented.

The mass of clay and sand is large, and cannot be compared to any mass of granite or of limestone which are found among erratics; but the Galena (Trenton) shales which are tougher than limestones are known to have been transported *en masse* by the Wisconsin glaciers. Bodies of this kind are known within the city limits of St. Paul, Minnesota. One is at St. Anthony Park station, and although it is much distorted, is yet mainly unmixed with foreign materials and is highly fossiliferous, It is exposed in four places within half a square mile. At Dale and Martin streets, a similar body covering an acre and possibly a much larger area, lies in the drift high above the horizon of the shales *in situ* as exposed in the region. At Stickney, Curtice and Concord streets, a somewhat smaller mass has been cut through by the Chicago and Great Western railway, and this mass preserves the stratification quite completely although the strata form a syncline and an anticline and overlap the till. These masses, however, have necessarily been transported more than one half or one or two miles from where they were dislodged.

The Cretaceous near Goodhue is very much tougher than the

shaly clays of the Galena (Trenton) at St. Paul. The clay strata when wet would scarcely fracture under any conditions and the sand strata between them, being largely not compacted, could allow them more free movement and keep the mass from breaking apart, as long as the strata remained approximately horizontal or compressed. Moreover there is little instead of much gravel and till associated with it into which it might have been jammed by the glacier. The condition of the glacier at the time when this mass could have been dropped where it now lies, is indicated by a fine example of an esker which lies about one mile west of south, looking like one of the sandstone buttes or a dolomite swell. The esker presents an abrupt slope on its northwestern front, and extends indefinitely to the southeastward. At the foot of the esker is an exposure of Saint Peter sandstone. The brow of the hill has been excavated for a sand pit, and the strata of gravel may be seen in it dipping gently on all sides into the hill. Thin strata of nearly pure sand, unlike anything but Saint Peter sandstone, are conspicuous. The depth of the gravel is about forty feet, but the loess covering obscures the form of the hill and conceals the most of the esker deposit. A similar esker lies nearly two miles farther in the same direction, standing west of the village of Goodhue. The eskers and the Cretaceous lie in line, and notably they are perched on the brow of sandstone hills, fronting northwesterly. Again, the height of these eskers contrasts with the thinness of the till, which is only one or two feet thick, as seen in cuttings in the region. The glacier which strewed débris thinly, and which scarcely drove the residuary clays from the rock surfaces beneath it, must still have been a gigantic ice mass to have built such eskers on the farther side of a broad valley. A clay mass such as the Cretaceous here, would have been comparatively slight when once loaded upon the ice.

It is not my intention to urge this hypothesis of glacial transportation, but it is worthy of remark that the successive loose sand and tough clay strata would have been the best adapted of any to be easily slid upon the glacier, to be transported without

disruption, and to be laid down without dissolution. The peculiar rolling up of sand strata into lenticular masses between clay strata might not be easily produced by any single continued thrust of an overlying glacier, but might easily be the result of successive reverse sliding movements.

Very little, if any, attention has been paid to this Clay Bank by geologists since N. H. Winchell briefly described it, but it is not without scientific interest in its present significance, whether it is Cretaceous or Pleistocene. It has also a high commercial value. Professor Winchell believed that this clay and sand deposit might extend over several square miles and he has represented about sixteen sections on the map of Goodhue county (*op. cit.*). He has described a number of observed and reported Cretaceous exposures as occurring from two to fifteen miles distant, but none of these afford the desired evidence. Clays like that at Clay Bank might of course be expected to occur in other places in the drift and only the occurrence of strata unquestionably *in situ* can prove the same to have been deposited as Cretaceous, not as Pleistocene, in this region. There are also two other deposits which may be mistaken in this region for Cretaceous. One, the ferruginous conglomerates of the oldest drift, a sort of residuum of the oldest till, occurs here and there. No ferruginous conglomerate nor any gravels were observed in the strata of the Clay Bank, and indeed none are known to be from Cretaceous strata. A more deceptive deposit in this particular region is the variegated clays of the Shakopee formation. Such an exposure is seen one mile north of Clay Bank station in a railway cutting, where three or four feet of clay strata cover the side of a dolomite swell. When weathered, this clay remains long intact, while the dolomite strata above and beneath it are reduced. It might then be mistaken for a Cretaceous clay.

There are no Cretaceous deposits known in southeastern Minnesota which are unquestionably *in situ*, although Cretaceous clays, with fish teeth and bones or fossil leaves in sandstone, are not infrequently discovered in any of the "northwestern drift" in Minnesota. Their occurrence does not prove the proximity

of Cretaceous strata. Other supposed Cretaceous rocks are very evidently not such. With the exception perhaps of the half square mile in Goodhue county, no areas should be indicated on the map in southeastern Minnesota either as known or probable Cretaceous. At, or a little beyond, the western border of the region herein considered, the first Cretaceous begins, *i. e.*, near New Ulm.

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Minneapolis, Oct. 17, 1898.

THE SILURIAN FAUNA INTERPRETED ON THE EPICONTINENTAL BASIS.

THE oceanic movements which brought the Ordovician period to a close are believed to have been such as to affect all continents in a similar manner. The transition period from Ordovician to Silurian was probably characterized by a special shrinkage of the earth, due to an effort at adjustment to the stresses that had been accumulating during the whole of Cambrian and Ordovician time. In this shrinking process it is assumed that the ocean basins were made deeper and their capacity increased so that the waters of the shallow seas lying upon the borders of the continents and reaching into their interiors to some notable extent, were drawn off, and the bottoms of these seas became a part of the dry land. It is assumed that the continental shore lines migrated oceanward until they no longer lay upon the continental platforms themselves, but upon their abysmal slopes, and the former broad, shallow-water tracts of the sea-shelves were reduced to narrow bands. With the destruction of these shallow seas upon the continental platforms, the multitudes of shallow-water organisms which had existed in them were largely forced into extinction.[1]

After the readjustment of the solid earth, the seas began again gradually to creep upon the continental platforms by means of the landward cutting of the sea-cliffs, by reason of the sediments carried down from the land and dumped into the ocean basins, and by reason of the gradual settling back of those portions of the crust which had been locally forced upward beyond isostatic equilibrium. With the continuation of these processes new sea-shelves and new epicontinental seas came into

[1] For a fuller exposition of this hypothesis see "The Ulterior Basis of Time Divisions and the Classification of Geologic History," by T. C. CHAMBERLIN, JOUR. GEOL., Vol. VI, p. 449.

existence, and grew in extent as the period advanced. These were the Silurian seas, and in them there evolved a new assemblage of shallow-water organisms, the Silurian fauna. This fauna was derived genetically from those remnants of the earlier Ordovician fauna which had happened to survive in favored localities, but with the very general expansion of the shallow waters, a great expansional evolution took place and many organic characteristics, showing a notable advance in differentiation beyond that of Ordovician time, came into existence and were characteristic of Silurian time.[1]

As the Ordovician waters were gradually drawn off from the continental platform, the once broad sea, extending from eastern Canada to beyond the present Rocky Mountains, with its wealth of organic life, was gradually contracted, and its life either gradually became extinct or was forced into modified forms or compelled to emigrate under unfavorable conditions. The remains of the last survivors, of this once magnificent fauna, within this area, are now found in the lower beds of the Medina formation in Virginia.[2] With the passing of these last survivors, the interior Medina basin became a lifeless tract so far as any evidence has been left to us, save for some low types of aquatic plants and a few worm burrows. It was probably an isolated basin.

With the encroachment of the Silurian sea upon the continent, a junction was at last effected with the Medina basin, and again marine conditions, and a marine fauna occupied the area.

The Medina fauna of New York,[3] which has been described from the upper beds of the formation, signals the return of the marine conditions. This fauna is a meager one containing but thirteen species, most of which would not be out of place in either an Ordovician or a Silurian fauna, but the presence of a

[1] See "A Systematic source of Evolution of Provincial Faunas," by T. C. CHAMBERLIN, JOUR. GEOL., Vol. VI, p. 597.

[2] STEVENSON, Proc. Am. Phil. Soc., Vol. XXII, pp. 142 and 150; Vol. XXIV, pp. 85, 87 and 94.

[3] Pal. N. Y., Vol. II.

species of the brachiopod genus *Whitfieldella* stamps the fauna as of Silurian age.

In the New York section, which is usually taken as the standard for our continent, the Medina formations constitute the lowest division of the Silurian system. The Clinton division following the Medina consists in New York of a series of strata diverse in character. There are beds of shale, sandstone and limestone, and one very persistent stratum is the fossil iron ore bed. This division was well named "Protean Group" by the early New York geologists. The characters of the strata are precisely such as one would expect to find in a series of beds deposited during a period of readjustment of local conditions.

The Niagara division of the Silurian, following the Clinton, essentially represents the period when local conditions had become readjusted and equilibrium established. It was primarily a limestone-forming period, and although the Niagara shales of New York are classed with the limestone, it would perhaps be more natural from a stratigraphic point of view to place them in the preceding division.

From the point of view here taken, it will be seen that the Clinton and Niagara cannot be considered as separate and distinct time divisions having the same significance throughout the entire area in America which was originally covered by Silurian waters. The two divisions, rather, exemplify two sets of conditions. In the Mississippi valley the Clinton period of readjustment was short, and is represented by a very thin series of sediments. The conditions of equilibrium, with clear limestone-depositing seas, very soon became established after the incursion of the Silurian waters, but in New York, in the region nearer the finally established shore line, this period of readjustment occupied a much longer time. In the southern Appalachian region the Niagara conditions seem never to have been attained. Indeed, since it was probably the last region reached by the encroaching sea, it is possible that even the Clinton conditions did not begin there until long after the Niagara conditions had become established in some other parts of the continent. Taken

in a time sense, the Clinton and Niagara divisions of the Silurian must be considered as a unit, the stratigraphic distinctions between the two being of but local significance.

In like manner the Clinton and Niagara faunas must be considered as a unit. To be sure there are species which in any given area are known only in the Clinton strata, and others which are restricted to the Niagara limestones; there are also species restricted to a single stratum of either one division or the other. From the very nature of the case this would be expected, because all organisms are not so constituted as to be able to adjust themselves to all conditions of environment. There are always sure to be local adaptations in any general fauna, to the varying local conditions both in time and space. And so we must look upon the general Silurian fauna of America, not as constituted of two sharply defined faunal divisions, the Clinton and the Niagara, but as being one composite faunal unit composed of numerous faunulæ, adjusted to a great variety of local environments.

The same general Silurian fauna which occupied so large a portion of the North American continent, also was present in other parts of the world. In Europe it is recognized with its local adaptations in England, in the island of Gotland, in Russia, in Bohemia and elsewhere. Many species are common to the Silurian beds of England and North America, and there are like relations between the faunas in America and other parts of Europe. In other parts of the world this same general fauna has been found. As far away as New Zealand,[1] a Silurian fauna has been studied, in which there are several species common to Europe and North America. These facts show that there must have been intercommunication between the Silurian seas of different parts of the world, and means of intermigration for the organisms which inhabited them.

Although it has long been recognized that some means of intercommunication between Europe and the interior of North America must have existed during Silurian time, the pathway

[1] Quart. Journ Geol. Soc. Lond., Vol. XLI, p. 199 (1885).

connecting the two regions has never been definitely located. During Ordovician time there was an open passageway through the St. Lawrence valley joining the interior epicontinental sea with the ancient Atlantic Ocean, but during the Ordovico-Silurian transition period, the Taconic range of mountains was elevated, and this passage entirely closed. The Appalachian land was the eastern barrier to the interior Silurian sea, and during this period this land was joined to the Laurentian land at the north. East of this land barrier the Silurian fauna occurs in the eastern provinces of Canada, but these eastern strata are not continuous with those in New York, and the communication between the two regions was not direct.

In a southern direction the Silurian strata thin out and become more clastic in constitution, indicating proximity to a shore line, and it is probable that even at this early period the western extension of the Appalachian land, described by Griswold[1] and Branner[2] was already in existence.

The western extension of Silurian strata cannot be definitely shown, but they are nowhere a conspicuous feature in the United States further west than Iowa. Beds in the far West containing the chain coral, *Halysites*, have been referred to this period, but usually upon insufficient evidence, for this genus is known also to occur in the Ordovician. In those rare instances where other forms have been found associated with the chain coral, they usually have been of an Ordovician rather than a Silurian facies. Nowhere in the great western region has the wonderfully prolific Silurian fauna of the East been found, and it is safe to assume that the greater part of this region was above sea level during Silurian time.

This leaves the North as the only available outlet for the interior Silurian epicontinental sea. A glance at the accompanying map (Fig. 1) indicating the distribution of the Silurian outcrops in North America, shows their northward extension. There is an extensive area in the region of Lake Winnipeg (XIII), one

[1] Proc. Bost. Soc. Nat. Hist., Vol. XXVI, p. 474.

[2] Am. Jour. Sci. (4), Vol. IV, p. 357.

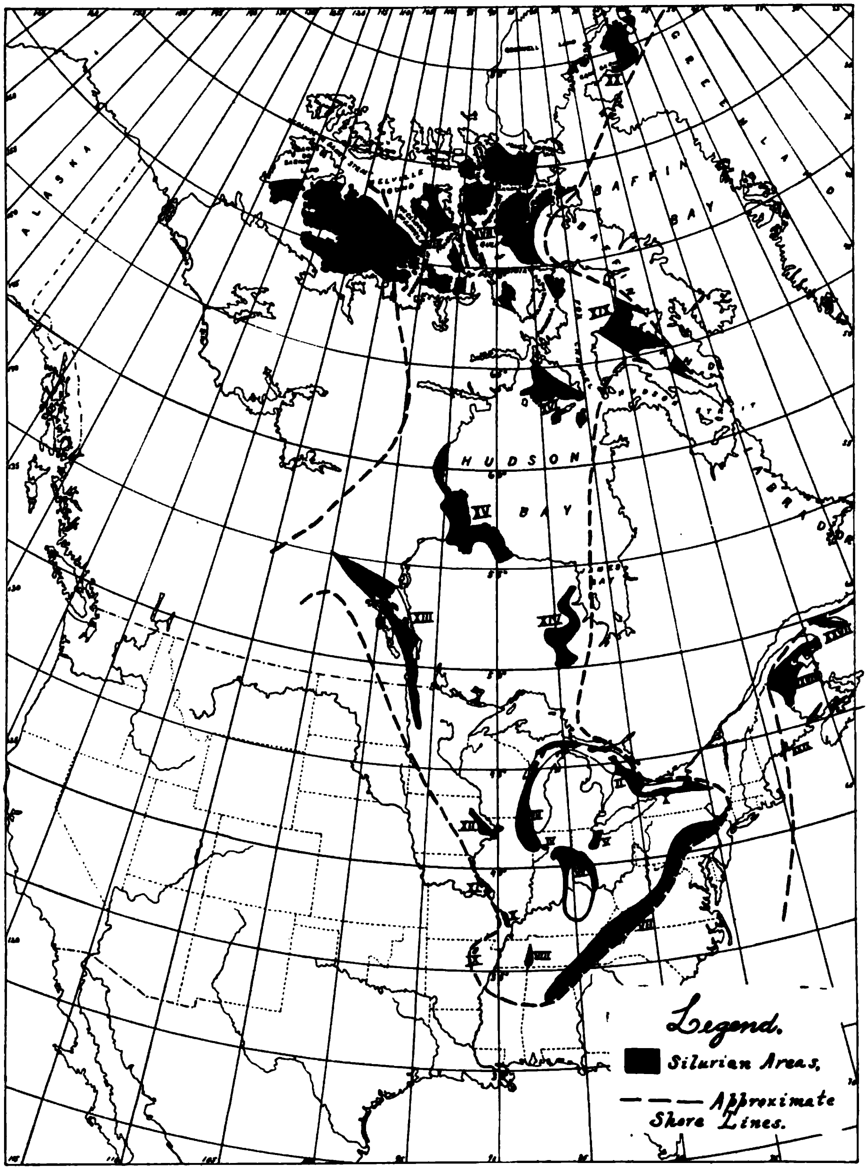

FIG. 1. Outline map of North America showing the position of Silurian outcrops and the hypothetical shore line of the Silurian epicontinental sea. The dark areas represent the Silurian outcrops, except in such instances as are specifically explained in the text.

near James Bay (XIV), and another along the western shore of Hudson Bay (XV). In all these regions the general Silurian fauna of America and Europe has been identified. The strata lie directly upon pre-Cambrian crystalline rocks, and as they could not have been deposited in these isolated patches, they must represent the remnants of a Silurian sheet which was at one time continuous and covered the entire intermediate region. Silurian strata have been recognized still further north on the islands at the mouth of Hudson Bay (XVI), and on the islands and mainland round about the Gulf of Boothia (XVII) and west of the Boothia peninsula (XVIII). In these two latter regions Silurian fossils have been found in abundance by several of the Arctic expeditions. From this general area Dawson[1] gives a list of thirteen localities from which Silurian fossils have been collected. If the region could be visited and properly studied, a prolific fauna would doubtless be secured. West of McClintook Channel the Silurian has not been properly differentiated from the Devonian, and Silurian fossils have not yet been found. In northern Greenland and in Grinnell Land (XX) Silurian strata with their characteristic fauna are known to exist.

Turning now to the map of the north polar regions (Fig. 2), it will be seen that the distance between northern Greenland (XX) and northern Russia (XXIII) where the Silurian fauna is known, is not extreme. At very near the halfway point between, lies Spitzbergen (XXI). The shores of these islands are known to consist for the most part of Palæozoic strata, and, although no Silurian rocks have yet been recorded from the islands, the presence of the Palæozoic strata is a connecting link across this little known Arctic region. In western Russia (XXIV) the Silurian strata are not exposed, but the area colored is occupied by Palæozoic strata of younger age than the Silurian, and is possibly underlain by the Silurian. The area in Russia between the regions marked (XXIII) and (XXIV) is occupied by Mesozoic strata, and the Palæozoic beds with the Silurian among them, doubtless underlie the whole region. The island of Gotland in

[1] Ann. Rep. Geol. Surv. Canada, new series, Vol. II, p. 45 R. (1887).

the Baltic (XXV) is constituted entirely of Silurian rocks, and one of the most prolific Silurian faunas known to exist in so small an area has been described from here.

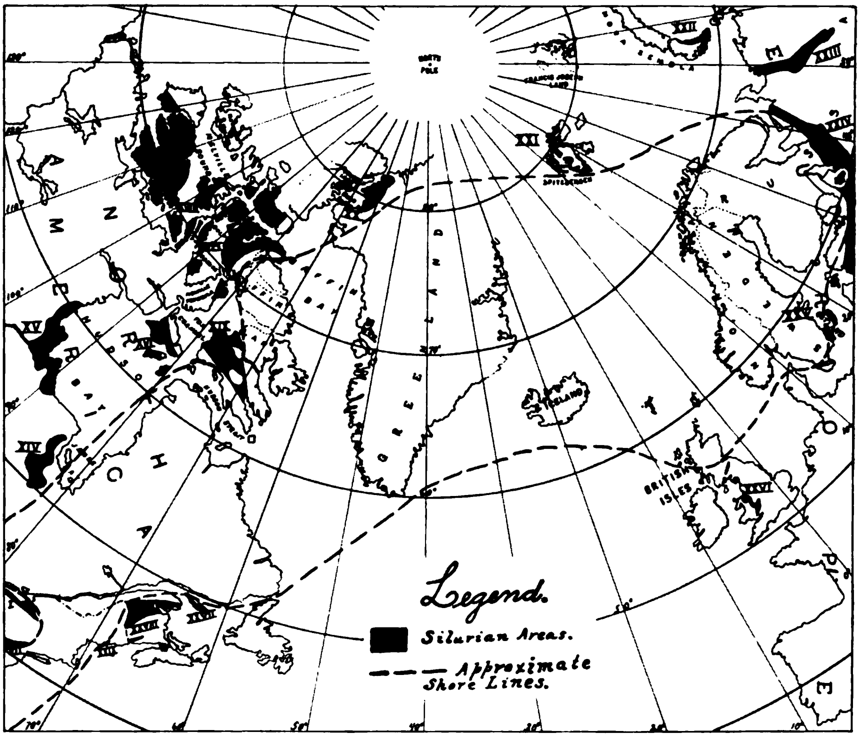

FIG. 2. Outline map of the North Polar regions with the Silurian outcrops and the hypothetical Silurian shore lines indicated.

The distributional evidence of the Silurian strata favorable to the existence of a north polar connection between the Silurian seas of Europe and those of the interior of North America having been pointed out, let us turn to the evidence of such a connection which may be afforded by the life of the period. A study of the Silurian faunas in the Mississippi valley, shows some remarkable points of resemblance with the faunas of north-

ern Europe, which are lacking in a comparison of the New York and the European Silurian faunas.

In the fauna of this age at Chicago and in northern Illinois, some remarkable forms of crinoids have been recognized which have not hitherto been recorded from America. One of these is *Crotalocrinus*, one of the most highly specialized genera of crinoids that has ever been described. Its arms, instead of being simply branched, as is usually the case, have the subdivisions joined laterally in such a manner as to form great, flat, flexible extensions from the body. It has been found most abundantly upon the island of Gotland, but it also occurs at Dudley, England, and is now found in the Chicago fauna. Two genera, *Corymbocrinus* and *Pycnosaccus*, founded upon Gotland specimens, are now found for the first time in America in the Chicago fauna. The first of these also occurs in England, but the second has been previously recognized only in Gotland.

Petalocrinus is another highly specialized crinoid genus with the arm branches from each ray consolidated into a triangular plate or "arm fan," so that the creature with its arms extended closely resembles the corolla of a flower with five petals. This peculiar genus was first described by Weller[1] from Iowa, and later a specimen was found from Indiana. The genus is now known to occur in Gotland, and several species have been described from there by Bather.[2]

Turning to the corals we find that the peculiar and highly specialized genus *Goniophyllum*, a quadrangular cup coral with an operculum of four triangular plates is found in England, Gotland and Iowa,[3] but is recognized nowhere else. The peculiar little twisted brachiopod, *Streptis*, known both from England and the continent of Europe, has more recently been recorded from the Silurian near Batesville, Ark.[4]

Now the presence of all these peculiar and highly specialized forms in various localities in the Mississippi valley and in

[1] JOUR. GEOL., Vol. IV, p. 167.

[2] Quart. Jour. Geol. Soc. Lond., Vol. LIV, p. 401.

[3] JOUR. GEOL., Vol. IV, p. 170.

[4] Am. Jour. Sci. (3), Vol. XLVIII, p. 329.

Europe, and their entire absence from New York where the fauna has really been more carefully studied than in any other part of America, is, to say the least, suggestive. If there had been a direct east and west pathway of communication between Europe and the interior of North America, why have not some of these forms also been found in New York, an intermediate locality which would have been in the direct path ?

Only a few of the more remarkable forms common to the Mississippi valley and northern Europe, but absent from New York, have been mentioned. There are many others in various classes, of a more modest and ordinary appearance, which need not be specifically mentioned here. The trilobites of the Chicago fauna, however, when properly studied, bid fair to bring out fully as remarkable points of relationship between the two faunas as the forms already mentioned.

The facts of the distribution of the life indicate clearly that northern Europe was more closely associated with the Mississippi valley than with the New York region in Silurian time. The sea-shelf connection must have been in either a southern, western, or northern direction from the interior of America. If it is shown that the Appalachian land extended westward across the southern part of the United States in Silurian time, the southern route is barred, but if that land was not present the pathway of intermigration would have been around the southern end of Appalachia and then north along its eastern shore and across to Europe. According to the mode of interpretation here adopted, it should have been, under these circumstances, along the sea-shelf of the north Atlantic, except as the species were adapted to pelagic migration, and as the Silurian strata in the eastern provinces of Canada lie in this path, some of the peculiar forms mentioned might be looked for in their fauna, but they are entirely absent so far as known. However, the stratigraphic evidence seems to shut off this southern route, because the Silurian strata grow thin in that direction and become more clastic, exhibiting every evidence of having been deposited near a shore line.

The western route need not be considered, because the Silurian fauna is not known to have any notable development in that direction. This leaves only the northern route. The presence in the Arctic localities of some of the peculiar genera already mentioned, would furnish the most substantial evidence in favor of this route. The conditions under which fossils have been collected in the Arctic regions have been such, however, that the fossil faunas of the far north are but poorly known. Although this is the fact, the genus *Crotalocrinus* has been identified from a small island in Wellington channel[1] from specimens of the stem alone. The stem of this genus, however, is quite distinctive, and the identification is probably correct. The other forms mentioned have not yet been found there, but they probably will be if the proper opportunity for the study of those faunas is ever offered.

If the interpretation here offered be the correct one, then the usual conception of the Silurian geography of North America must be somewhat altered. We must conceive of a North Polar sea with a great tongue stretching southward through Hudson Bay to about latitude 33°. There were doubtless islands standing above sea level within this great epicontinental sea, and at the latitude of New York there was a bay reaching to the eastward in which the Silurian sediments of the New York system were deposited. There may also have been a secondary tongue reaching southwestward from some point in Canada, into the Rocky Mountain region. Labrador, Greenland, and Scandinavia were in a measure joined into one great land area, though perhaps with its continuity broken, with a sea-shelf lying to the north of it and another to the south. Another epicontinental tongue of this northern sea extended south into Europe, bending to the west around the southern part of the Scandinavian land and connecting with a Silurian Atlantic Ocean. The sea-shelf to the north of the Labrador-Scandinavian land was a means of intercommunication between northern Europe and the interior of North America, and the sea-shelf to the south

[1] Quart. Jour. Geol. Soc. Lond., Vol. IX, p. 315 (1853).

of this land was a pathway between England and eastern Canada. Other tongues reaching to the south were probably present through Asia and through the Pacific Ocean, the New Zealand communication coming through one of these.

This interpretation of the Silurian, and similar interpretations of the other geologic periods, seem to call in question the generally accepted theory of the exogenous growth of the North American continent, and seem rather to point to an endogenous process of growth.

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BYSMALITHS.

A LACCOLITH as defined by Gilbert[1] is a body of igneous rock which has forced itself by intrusion, in a molten condition, between strata of sedimentary rocks in such a manner as to have lifted the overlying strata in a dome-shaped arch above it. The arching strata may be stretched and cracked to variable degrees and the molten magma may penetrate them to a greater or less extent according to the character of the rocks and the amount of cracking. A symmetrical dome may be the ideal form of a laccolith, but as Cross[2] has shown is rarely assumed because of the many modifying conditions attending the process. The principal ones are: a position of the plane of fracture along which intrusion takes place oblique to the bedding of the strata; lines of structural weakness in the strata; the presence of earlier intrusive bodies; the lack of coherence and of pronounced bedding in the strata invaded. Gilbert's use of the term laccolith embraced all lenticular bodies of igneous, intrusive rock occurring in stratified sedimentary rocks.

A laccolith is to be distinguished from an intrusive sheet of igneous rock, which also has been in most cases intruded between strata that were more or less horizontal at the time and required to be lifted by the force within the molten magma. The difference lies in the thickening of the igneous body into a more or less lenticular mass in the case of the laccolith, and in its retaining an almost uniform thickness in that of a sheet. In both cases the act of lifting the superincumbent strata must have been due to the same kind of force, namely, that exerted by a liquid under pressure upon the sides of a containing reser-

[1] GILBERT, G. K., Report on the geology of the Henry Mountains, U. S. Geog. and Geol. Surv. of the Rocky Mountain region, J. W. POWELL in charge. Washington, 1877.

[2] CROSS, W., The Laccolithic Mountain Groups of Colorado, Utah, and Arizona. 14th Ann. Rep. of the Director of the U. S. Geol. Surv., pp. 236. Washington, 1895.

voir. The difference in the results must be occasioned either by differences in the direction and rate of the intrusion, or by variations in the resistance offered by the overlying rocks. A sudden vertical thrust may lead to the arching of the strata immediately above its point of application. Local weakness of the strata may cause their elevation in particular places, as remarked by Cross. Another cause undoubtedly lies in the initial arching of strata brought about by other dynamic forces tending to bend and dislocate rocks. Such movements may be accompanied by extravasation of molten magmas which will follow planes of weakness in the dislocated rocks and will force themselves most readily where the rocks offer least resistance to displacement.

There is nothing in the petrographical characters of the rocks of intruded sheets and laccoliths in general to indicate any physical difference in the molten magmas from which each may have been formed. In both instances the magmas may have been equally liquid at the time of intrusion, or may have had similar compositions.

As regards their shape, it may also be noted that in sheets the lateral dimensions are very great in comparison with their thickness, whereas in laccoliths the thickness is much nearer the lateral dimensions.

Cross has shown that a certain amount of vertical displacement of the overlying strata may accompany their arching without changing the general character of the intruded body as in the laccolith of Mount Marcellina in West Elk Mountains, Colorado.[1] But, when vertical displacement with faulting is one of the chief characteristics of the intrusion, a distinction from normal laccolithic intrusion should be recognized. In the extreme this would result in the forcing upward of a more or less circular cone or cylinder of rock, which might be driven out at the surface of the earth, not necessarily in a coherent condition, or might be arrested at any stage of such extrusion and so might terminate in a dome of strata resembling the dome over a lacco-

[1] Loc. cit., pp. 182 and 236.

lith. By this mode of intrusion, the vertical dimension of the intruded mass becomes still greater as compared with the lateral dimensions, so that its shape is more that of a plug or core. Such an intruded plug of igneous rock may be termed a ***bysmalith*** (βύσμα = plug, λίθος = stone). There is then a transition from a flat, intrusive sheet to a laccolith with lenticular form, and from this to a bysmalith with much greater depth and considerable vertical displacement.

The resemblance of a bysmalith to a stock of igneous rock is such as to suggest at first their identity or close relationship. And though bodies of igneous rock may occur whose character might lead to their being classed with either of these types of intrusion, nevertheless it will be found advantageous to discriminate between bysmalith and stock by limiting the term stock to such bodies as occupy nearly vertical tubes or funnels of indefinite depth in rocks of any and all kinds, massive, schistose or stratified, and which maintain such a relation to them as to appear to belong to the category of dikes. Such tubes or funnels have been produced most probably by the enlargement of a fissure or a cluster of fissures by the carrying up of fragments torn from the walls. Stocks frequently represent the filling of a channel through which successive eruptions of magma have passed, as the conduit of a volcano. The formation of a bysmalith is more properly one act of eruption, and the solid rock removed is a block of nearly horizontal strata lifted at one time.

Examples of bysmaliths have not been described as such to any extent so far as the writer knows. Russell[1] has called attention to what he considers volcanic plugs in the region of the Blacks Hills of South Dakota and has suggested their recognition as types of intrusions different from laccoliths. But in his description of them he has mentioned nothing that demonstrates or even indicates that they possess the character of a plug. In each case they may be central remnants of small laccoliths. This is made probable by the position of the prismatic columns, which would be vertical in the central part of a laccolith, whereas

[1] RUSSELL, I. C., JOUR. GEOL., Vol. IV, p. 23.

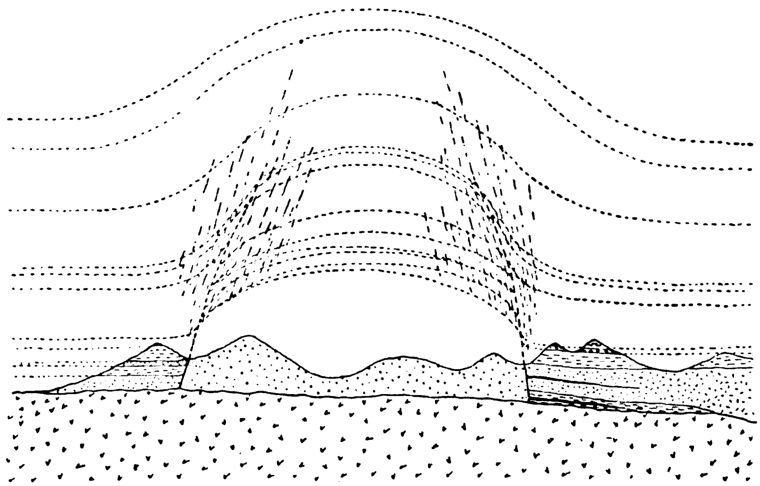
they should be horizontal in the body of a volcanic plug, and only vertical in the central part of its summit. In the case of Inyan Kara, mentioned by Russell, the dip of the limestone in the encircling wall, taken in connection with the diameter of the circle and the elevation of the igneous rock, is just what it might have been, had the igneous mass been a laccolith. The occurrences mentioned by Russell cannot be considered as illustrations of volcanic plugs without further evidence of their relations to the surrounding rocks.

In the Yellowstone National Park[1] at the southern end of the Gallatin Mountains, a great body of dacite-porphyry, three miles long and two miles wide, forms Mount Holmes and a group of mountains at the head of Indian Creek. In vertical extent the exposure of this mass is in all 2300 feet and throughout the exposure the character of the rock is so uniform as to indicate its being one mass solidified at one time.

Three quarters of the circumference of this igneous mass is in contact with stratified rocks, whose general position is nearly horizontal, but which in the immediate vicinity of the intruded body are bent abruptly upward, dipping away from it at steep angles. In several places the character of the contact plane is well shown, especially on the south side of the Dome, where a nearly vertical contact can be traced for almost a thousand feet. In each case the contact plane is almost vertical, inclining away from the intruded mass. From this mass small veins of igneous rock have penetrated the adjacent stratified rocks. The latter contained a large intruded body of andesite-porphyry in the form of a laccolith when the magma of the dacite-porphyry was intruded. The western boundary of the Holmes mass lies against gneiss and along a fault plane. An opening on this fault plane was probably the conduit through which the molten magma rose, for similar rock occurs along this fault line three miles to the north. While we have at present no knowledge of the configu-

[1] Geologic Atlas of the United States, Yellowstone National Park Folio, Areal Geology, Gallatin Sheet, Washington, 1896. See also the forthcoming monograph 32 of the U. S. Geological Survey on the Geology of the Yellowstone National Park chap. i.

ration of the bottom of the igneous mass, it seems quite probable that the magma spread in the shaly beds at the base of the Cambrian strata immediately over the nearly horizontal surface of the gneiss and beneath the laccolith already mentioned. The



Ideal section of the Holmes bysmalith.

thickening of the laccolith to the north and its contact with gneiss to the east may have hindered the further spreading of the later magma, resulting in a rupture of the overlying rocks in a block which was lifted by the intruding magma. The area of the block was more than five square miles and the vertical displacement more than 2000 feet, probably more than twice that height. Owing to the nearly uniform, crystalline character of the rock constituting the Holmes bysmalith, the grain being larger than that of the rock of the adjoining laccolith, there is little doubt that it solidified beneath a covering of strata. The slope of the planes of contact indicate that the intruded body possessed a steep dome shape, and the nearly horizontal position of the surrounding sedimentary rocks, at a little distance from the igneous body, prove that the arching of the strata took place at

a much higher horizon in the sedimentary terrane. The total thickness of beds, that were most probably superimposed on the gneiss at the time of the eruption under discussion, is about 9000 feet. These were lifted more than 2300 feet, possibly 4000 feet, and the position of the strata after the intrusion may have been similar to that shown in the accompanying figure, which corresponds in scale to the Holmes bysmalith. The section passes through Mount Holmes and Echo Peak, and does not intersect the conduit.

A more complex body of igneous rock closely related to a bysmalith occurs six miles farther north in the Gallatin Mountains at Gray Peak. It has broken across the strata and has forced into them numerous sheets of igneous rock. It is exposed at a much higher horizon than the Holmes bysmalith, cutting the Dakota conglomerate of the Cretaceous. Its position with regard to adjoining strata is not so well shown as in the case first described, however enough is exposed to prove its plug-like character.

It is probable that this type of intrusion will not be found to be as frequent as the laccolith, just as the latter is much less common than the intruded sheet.

The term *bathylith* has been proposed by Suess[1] for an intruded body having a more or less lenticular shape, which he considered to have been formed by intrusion of molten magma into a previously existing cavity made by the crumpling of the earth's crust. But, as Zirkel[2] has pointed out, the only difference between the bathylith of Suess and the laccolith of Gilbert lies in their mode of formation, their shapes being similar. It is questionable whether bathyliths defined in this strict manner exist. Indeed they probably do not. There has been a tendency among American geologists to use the term bathylith in a different sense from that in which Suess originally used it. This has been expressed by Dana[3] in his *Manual of Geology* in discussing the

[1] SUESS, E., Das Antlitz der Erde. Vienna, 1892, p. 219.

[2] ZIRKEL, F., Lehrbuch der Petrographie. Leipzig, Vol. I, p. 548.

[3] DANA, J. D., Manual of Geology, Fourth Edition, 1895, p. 811.

"granite-core" of the Sierra Nevada, California. "Such a mass of crystalline rock having irregular or indefinite outline has received the name of bathylith." This resembles the definition of stock given by Zirkel,[1] namely "stocks are irregular masses of considerable dimensions which, traversing the adjacent rocks without regard to their position, occur both in the stratified and massive terranes." However, it seems desirable to limit *stock* in the manner already suggested.

There is need for some general term that may be applied to large bodies of intruded rock whose exact character may not be evident, whose lateral extension may be quite irregular and whose depth may be profound. For such indefinite bodies the term bathylith may well be employed.

JOSEPH P. IDDINGS.

[1] Loc. cit., p. 544.

STUDIES FOR STUDENTS.

THE DEVELOPMENT AND GEOLOGICAL RELATIONS OF THE VERTEBRATES.

III. REPTILIA—(*Continued*).

ICTHYOSAURIA.

The *Icthyosauria* or *Icthyopterygia* were large marine reptiles fish-like in their external appearance, with the body and limbs modified to serve the purposes of the animal in its aquatic life. The head terminated in front in a long and powerful snout armed in most cases with sharp conical teeth set in a single common groove which bordered the jaws. The skull was flattened above and the eyes were large and protected by a ring of bony plates, the sclerotic plates. The body was naked or covered with fine scales that are never preserved in the fossil forms. The vertebræ of the tail were abruptly bent downward at the extremity. This is very peculiar because in most fossil forms in which the bending of the tail occurs, the bend is upward. The external form of the tail was as in the modern fishes. There was a dorsal fin as in the fishes and the limbs were converted into paddles with a large number of phalanges.

The *Icthyosauria* were long considered as the most primitive of the reptiles because of the general appearance of the body which is so fish-like and because the paddles were considered as the direct modification of the fish fin. The bones of the upper arm and leg are so short and the carpal and the tarsal bones are so simple, being mere disks of bone, that they were regarded as the first steps from the basal segments of the fin, while the numerous phalanges were regarded as the segments of the fin rays. Now, however, there is every reason to regard the *Icthyosauria* as the specialized descendants of land-living forms.

The degeneration of the limbs and the phalanges is exactly the same as took place in the mammals that have become aquatic in their habits; the seals, walruses and the whales.

The *Icthyosauria* are known only from the marine rocks of the Mesozoic time and chiefly from the Liassic division. Specimens are known from North America, Europe and England; Queensland, Australia; New Zealand and the East Indies.

Mixosaurus, from the Triassic of Besamo in Italy, is one of the oldest as well as one of the most important of the group. The animal was small, about three feet long, the head was proportionately long and there were few teeth; the legs were long and well developed, typically those of a land-living form.

Icthyosaurus.—This genus contained a very large number of species; it is generally divided into two groups, the *Longipinnati* and the *Latipinnati*, accordingly as the limbs, which in the whole genus have been reduced to the condition of paddles, are long and slender with few, five or less digits, or broad and short with more than five digits. Typical of the first division are: *I. quadricissus*, *I. tricissus*, *I. tenuirostris*, *I. longifrons*, etc.; of the second group, *I. communis*, *I. trigonus*, *I. leptospondylus*, etc.

The genus is found most commonly in the rocks of the Lias. From the Wellendolomite of the Black Forest and the Muschelkalk of Crailsheim of Wurtemberg comes one of the oldest as well as one of the largest of the genus, *I. atavus*, about thirty feet long. From the Trias of Spitzbergen have been collected two species, *I. polaris* and *I. Nordenskioldi;* the first was very large, while the second was much smaller. From the Lias of England come the best preserved specimens that we have. Especially is this true of the Lyme-Regis region of Dorsetshire. *I. communis* from this region belongs to the first division, the *Latipinnati;* it was one of the largest of the genus. To the same division belong from this region: *I. intermedius* and *I. breviceps;* to the second class, among others: *I. platyodon* and *I. tenuirostris*. The first was a giant even among these large forms, but the second was quite small and delicate in structure. The paddles

had only three digits or rows of phalanges. The skull was very long and slender and the jaws were slender and curved. The whole animal was about twelve feet long.

The continental forms come almost entirely from the Upper Lias, the Poisodonomyen-Schiefer. In Germany large numbers of most excellently preserved forms are obtained from near the small towns of Boll, Holzmaden, Ohmden, etc., at the foot of the Swabian Alps, and from the neighborhood of Banz in France. Many of the forms obtained from these localities are specifically identical with the forms from the English deposits. From the Cretaceous layers of Trichinopolis in the East Indies, and from about the same horizon of the same age in New Zealand and Australia have been collected specimens of this genus. From the Island of Gozo near Malta come fragments from layers that appear to be Miocene; if this is correct, the genus extends very much farther in time than was originally supposed, but the remains are only fragments and the age of the strata is still in doubt.

Opthalmosaurus from the Upper Jurassic of England is known only from a few fragments, but is interesting from the fact that the jaws were entirely without teeth. The paddle was broad and stout with many small phalangeal bones.

Baptanodon is from the Upper Jurassic of Wyoming. This genus was also without teeth. The paddle was very broad and the phalanges very numerous.

The great geographical range, and the large number of species indicate the extensive development of these animals in the short time that they existed on the earth. That they were fierce and predaceous is amply shown by the remains of fish scales and bones that are found in the coprolites.

SAUROPTERYGIA (*Plesiosauria*).

Aquatic reptiles, generally of large size, with long necks and heads of comparatively small size; the body very short and stout, ending in a long and powerful tail; the orbits were very small and the posterior portion of the skull shows a single tem-

poral arch. The teeth were sharp and strong, conical in form and often recurved; they were set in separate sockets or alveoli. The pectoral and the pelvic girdles in the most advanced of the group were greatly expanded to serve as a protective shield for the thoracic and the abdominal regions.

The *Plesiosaurs* descended from land-living animals with well developed limbs just as the *Icthyosaurs* did. In the earliest of the *Plesiosaurs* the fore and hind legs were those of an animal that walked on the dry land at least as well as the modern alligators, but in the later and more specialized forms, the limbs are reduced to paddles which were useless for any purpose but that of swimming. The general appearance of the brute has been aptly described as that of a "turtle strung on a snake."

There are generally recognized three families of the *Plesiosaurs:*

Nothosauridæ.
Plesiosauridæ.
Pistosauridæ.

Nothosauridæ.—These were small forms that were most nearly related to the parent form of the whole group. The limbs were more or less well adapted to progression on land and there were five functional digits on each foot.

Nothosaurus, from the Triassic (Muschelkalk) of Byreuth and from other parts of Germany and from the Tyrol and the Keupfer of St. Cassian in France, was one of the small forms. It was about nine feet long. The skull was long and flat. The orbits were small and were located in the middle portion of the skull. The temporal fossa was quite large, taking up the posterior third of the skull.

The anterior nares were small and located far forward but not at the extremity of the rostrum. The teeth were numerous, small, and of nearly equal size in the posterior portion of the jaws, they formed large recurved tusks in the fore part, and were set far apart. There were 20 cervical vertebræ, 25–30 dorsals, and about the same number of caudals.

Closely related forms from the same horizon, that are known

only from fragments, are *Chonchiosaurus*, *Simosaurus* and *Lamprosaurus*.

Lariosaurus was very much smaller than *Nothosaurus*, being less than 3 feet in length. It is known from the Trias (Muschelkalk) of Italy. The skull is triangular in outline and very much shorter than the skull of the first genus. The temporal fossæ are large, the orbits and the nares small and lying quite close together. There were 20–21 cervical vertebræ, 24–26 dorsal, and about 30 caudals. There was in this genus, as in the former, a ventral armor of small abdominal ribs.

Pachypleura, from the Trias of Italy, was very similar to *Lariosaurus*, but was even smaller. It was remarkable for the length of the tail which was nearly half as long as the body. There were about forty vertebræ in the tail. The same genus is known from the Trias of Germany.

Plesiosauridæ: large forms with the limbs developed as paddles. There were five digits on each foot, but the number of phalanges is much above the normal. The whole pectoral girdle reaches a very great development in these forms so that it forms a bony protection for the thoracic region.

Plesiosaurus.—The head of this genus was small and rather elongate, the temporal fossæ were large and the orbits and nares small. The teeth were numerous in both jaws. They were long and slender, slightly recurved and set in deep alveoli. They were somewhat large at the anterior end of the snout. The neck in some of the species of the genus, was as long as the rest of the body. There were 20–72 cervical vertebræ, 20–25 dorsals, and 30–40 caudals. There was a system of abdominal ossicles consisting of a centerpiece and two or more smaller lateral pieces. The most characteristic part of the anatomy of the animal is the pectoral girdle. The coracoids became very large and the clavicles reduced to small proportions. The extension of the coracoids of the two sides causes them to meet in the median line and they together join the clavicles and the interclavicle in front, making a thick bony cuirass covering the region. The pelvis does not show such a great expansion, but there is a

considerable development of the pubis, that parallels to some extent the extension of the coracoids.

The oldest known remains of this genus come from the Rhaetic beds of England and France (Autun). The most plentiful deposit is in the Lower Lias of Lyme-Regis in England; there are about twenty-six species known from these beds, a much larger number than is known from the continent. The continental forms are found most commonly in the Lias beds in the vicinity of Holzmaden in Germany and near Banz and Autun in France.

Eretmosaurus is quite similar to *Plesiosaurus*, being distinguished only by the greater development of the thoracic shield. A headless skeleton preserved in the British Museum is about nine feet long.

Cimoliosaurus from the Cretaceous of the United States is characterized by the complete loss from the pectoral girdle of the clavicles and the interclavicle. The scapulæ and the coracoids are extended until they meet the bone of the opposite side in the median line for a long distance and join each other in a broad suture. The whole arrangement is the most specialized of any in the group, both in the loss of the two elements and in the size of the coracoids and the scapulæ. Many similar forms that show the same thing, but with slightly different shaped bones, have been described as different genera, but were all united by Seeley in the genus *Cimoliosaurus* of Leidy. These genera are *Discosaurus*, and *Brimosaurus*, from the same horizon of the Cretaceous in Alabama and New Jersey as the original genus; *Polycotylus* from the Cretaceous of Kansas (Niobrara); *Elasmosaurus*, from the same locality and horizon as the last, is of remarkable length, one specimen from near Fort Wallace in Kansas being 45 feet long, the neck alone being 22 feet and containing 72 vertebræ; *Mauisaurus*, from the Cretaceous of New Zealand.

A summary of some of the different forms referred to this genus will give some idea of the importance it attained in the latter part of the Mesozoic time.

Cimoliosaurus, Cretaceous of New Jersey and Alabama.

C. (*Polycotylus*), Cretaceous of Kansas.

C. (*Mauisaurus*), Cretaceous of New Zealand.

C. (*Elasmosaurus*), Upper Cretaceous of Kansas.

C. (*Plesiosaurus*) ***helmerseni***, Gault of England and Russia.

C. (*Plesiosaurus*) *planus*, Gault of England, Russia, and France.

C. (*Plesiosaurus*) *australis*, Cretaceous of New Zealand and Australia.

C. (*Plesiosaurus*) *chilensis*, Cretaceous (?) of Chile.

The *Plesiosaurs* were powerful, free-swimming, predaceous animals that found their chief food supply in the fishes and the smaller reptiles that inhabited the same waters. The long neck and powerful teeth must have made them more than a match for any of the aquatic forms of the time, and the fish-like form and the strong paddles enabled them to get through the water with great velocity. In no other form of this time do we find such great variety of forms and such wide geographical distribution; the only region in which their remains have not been found is South Africa. A most interesting habit of the animals was the swallowing of stones, apparently to aid in the digestive work of the stomach. One specimen from the Fort Benton Cretaceous of Kansas had about 125 of these stones in the stomach, varying in size from that of the fist to that of a pea.

Thaumatosaurus, from the Jurassic (Dogger and Kimmeridge) of England and India (Gonwanda series), and also from the Jurassic of Wurtemberg, was a peculiar form with a very large head supplied with strong teeth and a very short neck. The limbs were proportionately quite long and the bones of the proximal series were better developed than common in the *Plesiosauridæ*.

Peloneustes and *Pliosaurus* are from the Cretaceous of England. The last was of gigantic size, the skull of one being over 4 feet 9 inches in length and 2 feet 11 inches across the posterior end. The neck was rather short having only about 20 rather compressed vertebræ.

Pistosauridæ: the skull, elongate and terminating in a sharp rostrum in front; the anterior nares, very small and formed by the maxillaries and the premaxillaries; the nasals, greatly reduced and taking no part in the nares; a single foramen in the palate at the anterior end, forming the posterior nares or choanæ.

Pistosaurus is the single genus; from the Muschelkalk of France and Germany.

PYTHONOMORPHA.

The *Pythonomorpha* are specialized forms of the *Lacertilian* branch developed during Cretaceous time. They were sea-living lizards, corresponding in many particulars to the popular idea of the sea serpent. They were greatly elongated in form, the limbs were specialized as paddles, and the whole body adapted to an aquatic life. They resembled the living *Varanus* or *Monitor.* The head was long and flat; the eyes, small and located far back in the skull, were supplied with sclerotic plates. The major part of the skull was formed by the long jaws, which were furnished with sharp, conical teeth, straight or slightly curved backwards, and set in separate alveoli. The upper jaw was solid and strong, with or without a rostrum extending in front of the teeth. The lower jaw was not united at the anterior end with the jaw of the opposite side, but was attached to it by cartilage, thus allowing a great degree of freedom in the action of the two jaws. Moreover, the jaw of each side was furnished with a second joint at about the middle, which allowed the jaw to be bent out or inward in a horizontal plane, and enabled the animal to swallow the large animals upon which it preyed. The brain cavity was small, and the quadrate bone was joined to the skull loosely, as in the snakes, allowing the jaws to be opened very widely. There were a great many vertebræ, giving a great length to the neck and tail as well as to the dorsal region. The vertebræ were furnished with very perfect articular surfaces, concave in front and concave behind; besides the regular arrangement for the connection of the vertebræ there were accessory articular processes such as occur in the

snakes, allowing a very great freedom of movement to the body. The limbs were modified as swimming organs. As in the case of land forms generally which have become adapted to an aquatic life, the number of the phalanges was increased, while the shape of these and of the tarsal and the carpal bones became indefinite, and, in some cases, they were even reduced to mere flattened disks of bone.

The geographical range of the *Pythonomorpha* is rather remarkable. They are known from the Upper Cretaceous rocks only, ranging from the Upper Dakota to the Lower Laramie. They have been found in the rocks of the western part of the United States, in Kansas and the Dakotas and in the Cretaceous deposits of New Jersey and Alabama; in the Maestricht beds, Lower Danian, of Belgium; in the Upper Cretaceous of England, the Chalkbeds, which are supposed to be correlated in time with the Niobrara beds of western Kansas; in Upper Cretaceous beds of unknown position on the coast of Chile and upon some of the adjacent islands, and in the same horizon in New Zealand.

The order is divided into three groups: the subfamilies *Tylosaurinæ*, *Platecarpinæ*, and *Mosasaurinæ*. Below is an abbreviated list of the characters assigned by Williston to the various divisions.

Tylosaurinæ: hind feet functionally pentadactyl; trunk short, tail proportionately long; tarsus and carpus almost wholly unossified, phalanges numerous; premaxillaries projecting as a long rostrum in front of the teeth.

Tylosaurus.—This is one of the largest of the forms. It reached in some cases, *T. dyspelor*, a length of nearly 30 feet. There were 7 cervicals, 29–30 precaudals, 80 caudals. From the Upper Cretaceous of New Zealand, Kansas, New Mexico, and New Jersey.

Hainosaurus: less well known; from the Upper Senonian of Cipley (Brown Phosphate Chalk) in France.

Platecarpinæ: hind feet functionally pentadactyl; trunk short, tail proportionately long; carpal and tarsal bones not well ossified; premaxillaries, not projecting in front of the teeth, obtuse.

Platecarpus.—This form was of intermediate size, one genus reaching a length of about 14 feet. Cervicals, 7; precaudals, 27–28; caudals about 80, probably somewhat less than in the *Tylosaurinæ*. From Kansas, Colorado, and Mississippi.

Plioplatecarpus: from the Maestricht of Belgium.

Taniwhasaurus: from the Cretaceous of New Zealand.

Mosasaurinæ: hind feet tetradactyl; carpus and tarsus fully ossified and with not more than six phalanges in each digit; trunk rather long with a shorter tail; rostrum short.

Mosasaurus: from Belgium, England, New Jersey, Dakota, Alabama, and North Carolina. Specimens from New Jersey show a length of 32–36 feet, and some of the European forms were as long as 40 feet.

Clidastes.—This was one of the smallest of the genera. *C. pumilus* was only about 6 feet long, and no species was over 12–14. Cervicals, 7; precaudals, 42; and caudals, 70. From Kansas, Colorado, New Jersey, Mississippi, and Alabama.

Many less well-known genera have been described from the rocks of this country and Europe, showing that the group had a considerable development while it lasted.

Speaking of the group, Williston says: "The food of the Mosasaurs must have consisted chiefly of fishes of moderate size with occasional victims of their own kind. While the flexibility and loose union of the jaws undoubtedly permitted animals of considerable size to be swallowed, the structure of the thoracic girdle would not have permitted any such feats of deglutition as the *Python* and *Boa* are capable of. The animals must have been practically helpless on land. They were not sufficiently serpentine to move about without the aid of limbs, and these were not at all fitted for land locomotion. They lived in the open sea, often remote from the shores. Their pugnacity is amply indicated by the many scars and injuries they received, probably from their own kind."

PTEROSAURIA.

The *Pterosauria* or *Pterodactyls*, as they are more popularly called, were reptiles that were adapted to a flying or soaring life

in the air. Just as the preceding groups, the *Icthyosaurs* and the *Plesiosaurs* had been compelled by the great struggle between the large number of reptilian forms to seek some peculiar modes of life to maintain an existence and had taken to the water, so these forms had been compelled to seek new environment and became adapted to an aërial, or partially aërial, life. Whether they were possessed of any great power of flight or were only capable of soaring, as the flying-squirrel, is not known, but the enormous distance that their remains are found from what must have been the land at the time and the pneumaticity of their bones speak for a very well developed power of flight. There was great variation in the sizes of the animals, some being very small, while others reached a spread of 18 feet from tip to tip of the expanded wings. The bones were all hollow and provided with foramina at the extremities that seem to have filled the same function that the foramina in the bones of the birds do, that of supplying air to the interior of the bones. These two facts seem to imply that the Pterodactyls were warm-blooded, but this can not, of course be definitely settled from the skeleton. The tail was either long or short. In the cases where it was long, it ended in an expansion that served as a rudder to guide the flight of the animal. The fore limbs were very much longer than the hind limbs and were especially modified to support the organ of flight. This was a strong membrane much like that which serves the same purpose in the bats. In certain of the specimens preserved in the fine grained slates of the Solenhofen beds, the folds of the wings are preserved and even the course of the nutrient arteries may be followed. There were four digits on the front foot or wing, the last four, and the last of these, or the little finger, was enormously extended so that it was many times the length of the arm. The other fingers were short and greatly reduced in size; they ended in small claws which perhaps aided the animal to cling to the sides of the cliffs on which it lived. The wing membrane stretched from this extended finger and the arm to the weak posterior limbs. In all probability the membrane extended also between the

hind legs and for a short distance out upon the tail. The head was very bird-like, all the bones being closely united and the sutures between them disappearing early in the life of the animal. The skull was of many different forms in the different species and the jaws were almost always furnished with teeth, but in some of the more specialized of the genera these were absent.

The group is generally divided into three families:

Pterodactylidæ.
Rhamphorynchidæ.
Pteranodontidæ.

Pterodactylidæ: forms with short tails; the skull quite long and furnished with teeth; the sides of the skull anterior to the orbits broken by vacuities that possibly aided in lightening the weight of the skull. The orbits were large and there was only one temporal arch. The metacarpals were longer than one half of the length of the forearm.

Pterodactylus was about a foot long and very slender in all of its proportions. The skull was long and bird-like and furnished with teeth at the anterior ends of the jaws only. There are many species of this genus known, the most of which come from the Upper Jurassic layers (Lithographic slates) of Germany, near Eichstat and Bayern. A few specimens have been taken from the Upper Jurassic of France in the department of Ain and the Kimmeridge clays of England have furnished isolated bones of the same genus.

Rhamphorynchidæ: forms with long tails which are frequently accompanied by ossified tendons; the skull only moderately elongate; the jaws furnished with teeth throughout their whole length which grew smaller towards the posterior part of the jaw, those in front being long and slender. Metacarpals shorter than the half of the forearm. The fifth toe of the hind foot taking some part in the support of the wing membrane and showing a much greater development than the other toes.

Dimorphodon, from the Lias of Lyme-Regis in Dorsetshire, England, was a much stouter form than the *Pterodactylus;* the

head was short and high with strong teeth and small lateral vacuities. The whole animal had a length of nearly three feet.

Rhamphorynchus had a rather long snout, edentulous at the anterior end in both the upper and the lower jaws. The remaining portions of the jaws were filled up with rather long and slender teeth which were directed forward. The teeth were of different sizes in the jaws, but, in general, the largest were in the anterior part. The neck was short and strong and the cervical vertebræ very short. The sternum was broad and furnished with a median keel for the attachment of strong muscles as in the modern flying birds. The tail was long with 30–36 vertebræ and strengthened by tendons. The wing of this form was more slender than in the majority of the *Pterodactyls* and resembled that of the night hawk or goatsucker. The genus is known from the Upper Jurassic (Lithographic Slates) of Bayern and Wurtemberg.

Scaphognathus was much like the preceding, except that the teeth extended to the extremities of the jaws and were few in number. They were directed vertically instead of forward. Specimens of this genus are known from the Upper Jurassic of Germany and of England.

Ornithochierus is the name given to a very large form that is known from numerous fragments in the Jurassic deposits of England. The jaws seem to have been furnished rather sparsely with teeth of considerable size which extended to the extremity of the jaws. There are a great many species represented in the rocks of England from the Wealden to the Cretaceous, in all about 25. One form from the Chalk, *O. giganteus*, must have possessed a spread of wing of about 15–18 feet.

Pteranodontidæ: the skull long and terminating in sharp, edentulous jaws; no lateral vacuities in the skull; the tail, short.

Ornithostoma was originally described from the fragment of a jaw from the Chalk of England, but no more of it was known than that it was without teeth.

Pteranodon (?), from the Upper Niobrara, Cretaceous of Kansas, was a very large form with toothless jaws; probably

synonymous with *Ornithostoma*. Head much elongate; the jaws slender, pointed and wholly wanting teeth; external nares and antorbital vacuities united; supratemporal fossa of large size; occipital crest elongated; the anterior dorsal vertebræ united and bearing a supraneural plate for articulation with the scapulæ; tail short and small; four functional toes on the hind foot.

Speaking of the general appearance of the animal, Dr. Williston says: "Altogether the skeleton of *Ornithostoma* presents some remarkable characters. I believe there is no other reptile in which the prosthenic features are carried to as high a degree as in this. The disproportion between the fore and hind extremities is almost ludicrous. The pelvis is exceedingly small, the legs not only small but weak in all respects. That the animal could have stood on its feet free on the ground I do not believe possible. The neck vertebræ are relatively stout, but the neck was not remarkably elongated, to carry such a head as the animal possessed. Furthermore, the remarkable mode of articulation of the neck and the anterior dorsal vertebræ seem to indicate a restricted range of torsion, though tolerably wide sagittal flexion. The occurrence of the remains of the large species in strata evidently formed remote from the shore lines, as shown by the absence of other animals, turtles, etc., indicates great powers of flight. Furthermore, it is rare that a single bone of a *Pterodactyl* is found unassociated with others, and almost invariably the wing bones are found more or less in connection, indicating either tough and horny tendons or a rapid sinking in the water, which might happen from the filling of the hollow bones with water through their pneumatic openings.

"Notwithstanding the enormous expanse of the wings, I do not think these animals could have weighed much when alive. I doubt very much if one of the largest species reached twenty pounds."

Nyctodactylus was a form from the Cretaceous of Kansas (Niobrara) that differed from the previous genus principally in the size, the wings measuring less than ten feet when expanded. The jaws were almost certainly edentulous.

TESTUDINATA.

The turtles may be briefly described as reptiles that have lost the teeth completely, and have developed an external skeleton in the shape of a bony case that is more or less complete and protects the body of the animal. There is little doubt that they are derived from animals that did not possess such a structure, but the point of their divergence from the primitive stem is so ancient that it has not yet been detected, and the oldest form that we know is a member of the most specialized group of the turtles.

The order is generally divided into three suborders:

Trionychia.
Pleurodira.
Cryptodira.

The *Tryonichia* differ from the typical forms of the *Testudinata* in that the bony exoskeleton is largely represented by a thick, leathery skin, which has given them the name of Soft-shell Turtles. Beneath this skin is developed a series of small bony plates with a characteristic sculpture, that in many places form the chief remains of the forms.

Trionyx is the most common of the extinct forms. The oldest remains are from the Upper Cretaceous of New Jersey; these are, for the most part, fragmentary remains of the plates of the carapace. From the Upper Cretaceous, Laramie, of the western part of the United States and British America, have been collected a large number of specimens. Through all the deposits of Tertiary age in Europe, specimens of this genus have been found; in the United States it is found throughout the Tertiary of the eastern part, but in the west seems to be confined to the lower layer, the Eocene. Remains of still living species have been found in the Pleistocene beds of India and Burmah.

The *Cryptodira* are by far the most important group of the Testudinata, both in number of species and their distribution in time. The group is characterized by the fact that the pelvic bones are not anchylosed to the carapace and the plastron above and below. There were developed so many forms that it is

impossible to consider more than a few of the genera. There seems to be a division of the group in very early times into land-living and water-living forms. The first of these gave rise to the common swamp and land turtles of today, and the second group to the sea turtles, the *Pinnata*.

The second of these groups may be considered first; *Dermochelys* is the most specialized of the genera. This is a gigantic form still living in all of the oceans, though little known from its almost exclusively pelagic habits. The carapace has entirely disappeared and is replaced by a tough leathery skin that has won for them the name of "Trunk-backs or leather-turtles." The plastron is less completely removed but there is a large space in the center, between the bones called the fontanelle. The fore limbs are developed as flippers, the anterior pair being much the longest.

The more common members of the same division are the Loggerhead and Green turtles. In these the carapace and plastron are less reduced, but both show large vacuities that indicate the steps by which the condition in *Dermochelys* was produced.

Protostega is the earliest of the definitely known forms. It is from the Upper Cretaceous (Niobrara) of Kansas. Similar in many respects to the recent *Dermochelys*, it still shows many primitive characters that indicate its separate position. The carapace was not ossified, but the proximal ends of the ribs show lateral expansions that would, if carried a little farther, produce the condition found in the *Chelonia* (the most primitive of the living sea turtles). The genus was one of the largest of the order. One specimen measured nearly or quite seven feet in length.

Protosphargis, from the Upper Cretaceous of Italy, *Eosphargis*, from the London Clay (Eocene), and *Psephophorous*, from the Miocene of Germany, are all closely related to *Protostega* and show successive steps toward the condition of *Dermochelys*. The great geographical extent of these forms seems to indicate that they possessed the same roving and pelagic habits that characterize their nearest living relative.

Remains of the closely related forms that culminated in the Cheloniidæ (*Chelonia*, etc.) and differed from the previous forms only in the more complete carapace, are found in the Cretaceous of Europe and America. These forms show characters of the land turtles as well as of the sea turtles, and are in all probability the forms that represent the branching of the primitive stem of the turtles. Such forms are *Propleura*, from the Cretaceous of New Jersey, *Osteopogys*, from the same locality, *Toxochelys*, from the Niobrara, Cretaceous, of Kansas, and *Euclastes* from the Cretaceous of New Jersey, the Greensand of Cambridge, England, the Eocene of England and France. Forms more common on the continent are *Eurysternum*, from the Upper Jurassic of Germany, *Idiochelys*, from the same horizon in France (Cerin) and Germany (Kelheim). *Hydropelta* is quite frequently found associated with the remains of *Idiochelys*.

Of the common swamp and land turtles more is known than of the sea turtles. The ancestors of the *Chelydridæ*, or common snapping turtles, are found as far back as the Upper Jurassic. *Platychelys* from this horizon, at Kelheim, is one of the typical forms. In *Platychelys* there was an extra pair of plates in the plastron, the mesoplastra, that did not reach the middle line from the sides.

Helochelys, from the Greensand (Cenomanian) of Kelheim, was quite similar to the preceding. The whole surface of the carapace was covered with wart-like projections, except the lines that marked the union of the horny plates with the bony ones beneath. In this form the mesoplastron was narrow but complete, and extended from each side, meeting in the middle line. It was quite large, about a foot and a half long.

Compsemys is a very large form, distinguished by the fact that the plates of the carapace are joined by suture to the peripherals, and are marked by small pit-like excavations. It is very plentiful in the Upper Cretaceous layers (Fort Union and Laramie) of the western part of this country.

Anostira was a small form from the Lowest Eocene (Bridger) in Wyoming.

Apholidomys and *Pseudotrionyx* are from the Eocene of France. The true land turtles, *Testudo*, mostly, are characterized by the great elevation of the carapace and the smoothness of its bones. The claws of the toes are in many cases shortened till they appear as broad nails. The earliest forms known are from the Eocene of Wyoming and New Mexico, the Wasatch and Bridger. In Europe the earliest forms occur in the Oligocene. Throughout the Miocene and the Pliocene layers of both the old and the new world, the genus abounds. The best region for the remains, however, is the Bad Lands of South Dakota, Miocene or Oligocene, where they occur in great abundance.

Especially remarkable was the gigantic *Collosochelys* of the Siwalik Hills of India (fresh-water Miocene). The animal was fully 18–20 feet long, the carapace alone being 12 feet long and 8 feet high.

From the Pleistocene of Queensland, Australia, comes the peculiar form *Meiolania*, which possessed horns or bony protuberances on the skull.

During Pleistocene times many of the islands of the East Indies were inhabited by enormous land turtles. Remains of such are known from Mauritius and Rodrigues. Similar remains are known from the Island of Malta and on the Galapagos Islands off the coast of Central America there are still living forms of the same group.

The *Pleurodira* are the forms in which the bones of the pelvis are joined by sutural union to the bones of the carapace and plastron above and below. They are few in number in recent times, and were little if any more numerous in past time, though, peculiarly enough, the most ancient turtle known is a member of this suborder. *Proganochelys*, from the Upper Triassic (Keupfersandstein) of Germany, *Plesiochelys*, from the Upper Jurassic of England, and *Bothremys*, of the New Jersey Cretaceous, are also members of the same group.

PROGANOSAURIA.

These forms are of the greatest interest from a phylogenetic standpoint. They are generally regarded as the most primitive

form of the reptiles, and from them are probably derived the majority of the reptilian orders. They are characterized by a very generalized structure of the skull and skeleton that in many regards closely approximates the condition of the *Amphibia*. The bones were not completely ossified; there were many abdominal ossicles, and the vertebræ were perforated for the passage of the notochord. The group is extinct.

Paleohatteria, the earliest of the order, is found in the Rothliegende, Upper Permian, deposits of Niederhasslich near Dresden. It was a small lizard-like animal about a foot long; the teeth were small and conical, and were developed on the vomer and palatine bones of the mouth as well as in the jaws, a character common in the *Amphibia*.

Proterosaurus is another form much longer and more slender, about six feet in length. It is peculiar in the fact that the vertebræ of the neck are only seven in number, and are greatly elongated, as is common in the long-necked mammals. It is from the Keupferschiefer of Thuringia.

Mesosaurus, from the Permian or Permo-Triassic of South Africa, is represented by the impression of the anterior half of an animal that was much like the Plesiosaurs in general appearance; the neck was long and slender, and the head had the same kind of teeth. The posterior portion of an animal that is regared as belonging to the same genus has been found in the Permian of Brazil.

RHYNCHOCEPHALIA.

The members of this order differ only in degree from the preceding. The bones are better ossified; the abdominal ossicles are reduced in number and simplified in arrangement; the notochordal opening in the vertebræ is smaller and the skull has advanced toward the modern type of the reptiles. The group is of great importance, both because of the variety of the forms produced and because it is in all probability the direct ancestor of the later reptiles. The living *Lacertilia* and *Ophidia*, and, in all probability, the *Testudinata*, as well as the extinct *Plesiosaurs*, *Icthyosaurs*, *Pythonomorpha*, *Pterosauria*, *Dinosaurs*, *Croco-*

dilia, and possibly the *Theriodonta* must be regarded as the descendants of this order. Through the *Dinosaurs* the Birds are related to the order, and through the *Theriodonta* the Mammals.

Rhynchosaurus and *Hyperodapedon* are two forms from the Triassic, Elgin Sandstones of Scotland and the Triassic beds of Warwickshire in England. The latter genus has also been described from the Maleri, Triassic, beds of the East Indies. They were small forms, quite similar in external appearance to the modern lizard, except that the incisor teeth of the jaws were developed as great curved processes. The roof of the mouth was covered with teeth, and there was a single external nostril.

Homœosaurus and *Sapheosaurus* are from the Upper Jurassic of Germany and France, notably the Lithographic Slates of Kelheim. They were very similar to the modern lizards in appearance.

Sauranodon, from the Jurassic of Cerin in France, was similar to the foregoing, except that the jaws were greatly extended and were edentulous.

Champsosaurus, from the Upper Cretaceous, Laramie of Wyoming, and the lowest Eocene, Puerco of New Mexico, and *Simœdosaurus*, from the Eocene of France and Belgium, are very peculiar in that the articular faces of the vertebræ are nearly flat, instead of being deeply concave, or even perforated, as in the majority of the *Rhynchocephalia*. It has been suggested that the two forms are identical, but as the skull of *Champsosaurus* is not known it is impossible to settle the question. The skull of *Simœdosaurus* was long and slender, with an anterior rostrum much like that of the modern Gavial of the Indian rivers.

Sphenodon, from New Zealand, is the single living member of the order. It probably appeared in the Jurassic, though it is still unknown in the fossil state.

The modern *Lacertilia* and *Ophidia* are the direct descendants of the *Rhynchocephalia*. The chief differences are the loss of the lower one of the temporal arches (in some cases of both) and the loss of the abdominal ossicles. Moreover, the deeply biconcave character of the vertebræ, amounting in most cases to a

perforation of the centrum, is absent in most of the *Lacertilia* and all of the *Ophidia*. The loss of the limbs in the snake is but a secondary character, and is nearly accomplished in many genera of the lizards.

The earliest of the *Lacertilia* is from the Isle of Purbeck in Dorsetshire, England. All that is known of the specimen are the imperfectly preserved remains of the skull and some of the scales. The genus is called *Macellodon*.

Hydrosaurus, from the Lower Cretaceous of the Island of Lesina in the Mediterranean, was very similar in appearance to the modern monitors. (This genus was the direct ancestor of the great, specialized group of the *Pythonomorpha* developed during the Cretaceous.)

Dolichosaurus and *Coniosaurus*, from the Upper Cretaceous of England, and *Tylosteus*, from the Cretaceous of North America, are typical lacertilians. The Tertiary rocks of both hemispheres abound in the remains of the *Lacertilia*. The development of these forms began so early that even in the earliest Eocene we find representatives of the families and even of the genera of today. Zittel in his *Handbuch* enumerates from the Eocene of Wyoming the remains of *Chameleo*, *Iguanavus*, *Glyptosaurus*, *Saniva*, *Xestops*, *Thinosaurus*, and *Tinosaurus;* from the Eocene Phosphorite (Upper Eocene) of Quercy, *Agama*, several genera of the *Iguanidæ*, *Paleovaranus*, and *Lacerta*.

In the Miocene deposits of Europe are found many of the existing genera. In the Miocene of the western states, especially Colorado, are found such genera as *Exostinos*, *Aciprion*, *Diacium*, *Platyrachis*, and *Crematosaurus*.

Most of the remains of the Pliocene and the Pleistocene formations belong to existing genera and species, with the exception of the Australian *Megalania* and *Notiosaurus*.

The *Ophidia* are very poorly known from the fossil forms. The only parts preserved are the vertebræ. With the single exception of *Symoliophis*, from the Cretaceous of Charente, the known fossils are from the Tertiary layers. From the London Clay (Eocene) and the Eocene sand of France come the remains of

large Python-like forms. The Eocene of New Jersey has yielded one form, *Titanophis*, and the Puerco of New Mexico *Helegras*. The Eocene of Wyoming has yielded *Boavus*, *Lithophis*, and *Limnophis*.

The Miocene layers of both this country and Europe have afforded many scattered fragments that belong mostly to living families. The Pliocene and the Pleistocene contain only genera and species of living forms.

CROCODILIA.

The *Crocodilia* are lizard-like forms of generally, large size possessing many characters that indicate their origin from the *Dinosaurs* and the *Rhynchocephalia*. The tail is long and powerful, the jaws armed with strong, simple teeth, the skull flattened, and the anterior end produced into a rostrum of varying length; there is generally developed in the skin a series of bony plates that in some forms is confined to the back, and in others extends to the skin of the abdomen as well; there are generally developed abdominal ribs in the body wall.

The order is divided by Zittel into three suborders:

Parasuchia.
Pseudosuchia.
Eusuchia.

The *Parasuchia* are the nearest of all the order to the ancestral stem of the *Crocodilia*. The possession of paired anterior nares, located far back on the upper surface of the skull, of large preorbital openings in the skull; the structure of the base of the skull and the palatal region, and the structure of the shoulder girdle are all characters that unite the suborder with *Dinosaurs* and the *Rhynchocephalia*.

Belodon, the most common form, was about nine feet long; the skull extended forward in a long, high, and laterally compressed rostrum; the jaws were filled with strong, simple teeth; there were two rows of plates extending down the middle of the back, and others less regularly developed in the skin of the sides; the limbs were weak and probably had about the same

proportions as in the modern Crocodile. Remains of the genus are known from the Trias of Germany, and from the same horizon in both the eastern and western parts of the United States.

Stagonolepis and *Parasuchus* are forms separated from the foregoing by minor characters of the skull and teeth. The first is known from the Triassic (?) Elgin Sandstones of Scotland, and the latter from the same horizon, Maleri Sandstone of the East Indies.

Pseudosuchia.—These are very peculiar forms from the Triassic rocks; the genera were all small, not over a foot long at the outside; the most characteristic thing about them was the development of a cuirass of bony plates in the skin, that protected every part of the body from the head to the tail, and included the ventral as well as the dorsal side of the body.

Ætosaurus, from the vicinity of Stuttgart in Germany, is the best known form. A single slab in the Stuttgart Museum has the remains of twenty-four individuals preserved in it.

Typothorax is the name given to a form described by Cope from fragments of the ribs and the dermal plates discovered in the Triassic rocks of New Mexico.

Eusuchia.—This suborder is in general characterized by the shortness of the premaxillaries and the location of the external nares far forward on the snout; the roofing over of the palatal portion of the mouth by the gradual extension inward of the palatine and maxillary bones, and the crowding of the internal nares back toward the posterior part of the mouth. There are two sections described, the *Longirostres* and the *Brevirostres;* the first possesses a long, slender rostrum formed by the extension of the maxillary bones; the anterior nares are not divided at the anterior extremity, and the teeth are little differentiated. The *Brevirostres* have a short snout, with the anterior nares divided, and the teeth more or less differentiated.

The *Longirostres* contain several families, typical of which are the *Teleosauridæ* and the *Gavialidæ*. The *Teleosauridæ* are the oldest known of the *Eusuchia*, specimens being known from the Lias. The oldest of the forms were marine, and the latter

inhabited fresh water. They were powerful swimmers, with much better developed limbs than the modern Crocodiles. The skin of both the back and abdomen was strengthened by the presence of bony plates that formed a very perfect armor. Prominent forms were *Pelagosaurus* from the Upper Lias of Germany and France; *Mystriosaurus*, from the same horizon in Germany; *Steneosaurus*, from the Upper Jurassic of England and the continent; *Teleosaurus*, from the same horizon and localities, etc. Many genera are known from layers younger than the Jurassic, and these seem to lead naturally to the *Gavialidæ*, which are known from the late Tertiary of India, and are found living in the rivers of that country.

The *Brevirostres* became prominent in the Upper Jurassic, and occupied a very important part in the later times. Of five families described two are still living.

Alligatorellus was a small form from the Upper Jurassic of France; it was less than a foot long, and was characterized by the possession of biconcave vertebræ.

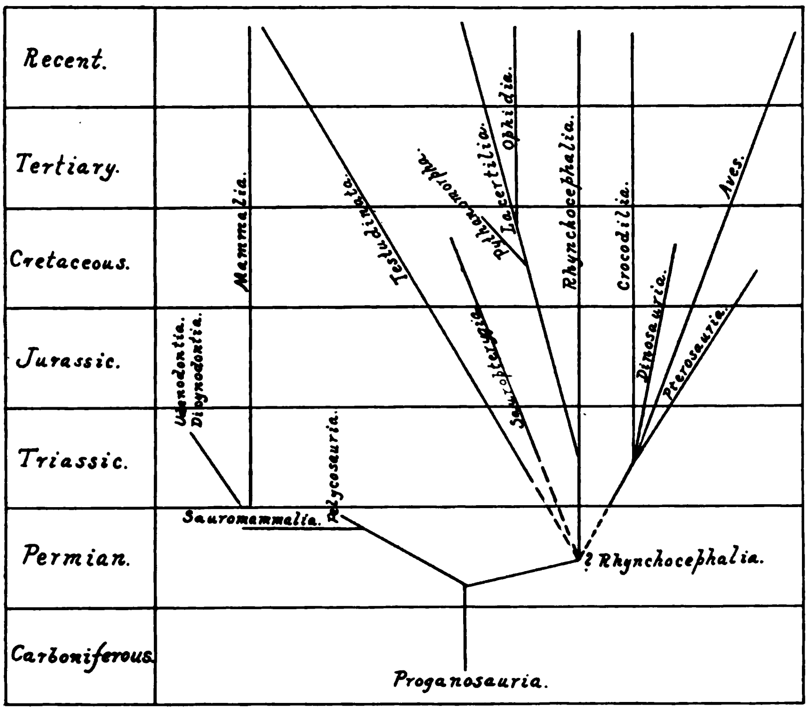
Goniopholis, from the Upper Jurassic of England and the continent, was a much larger form than the preceding. It possessed biconcave vertebræ; there was a double line of dermal plates in the skin of the back, and the ventral surface of the body was protected by a large number of plates joined by suture. Similar forms have been described by Cope and Marsh, from the Jura of the Rocky Mountains, under the names *Amphicotylus* and *Diplosaurus*. These may be synonymous with *Goniopholis*.

Bernissartia is from the celebrated fossil region near Bernissart in Belgium. It is characterized by the fact that the teeth are differentiated into separate sizes in the jaws. *Theriosuchus*, from the Purbeck of England, is regarded as belonging to the same family.

The true Alligators and Crocodiles appeared in the fresh water deposits of the Cretaceous and extended to the present time. *Diplocynodon* is one of the earliest of the true Alligators. Remains are found in the deposits of both Europe and North America.

The genus *Crocodilus* appeared in the Cretaceous of France. Remains are known from the Tertiary deposits of both the old and the new worlds as late as Pliocene time, when they seem to have disappeared from all regions except those in which they are still found, tropical Africa, South America, and the East Indies.

The connection between the various groups of reptiles may be seen from the following table, which is slightly modified from one published by Baur.



E. C. Case.

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EDITORIAL.

ASTRONOMERS are not alone in appreciating the interest which attaches to the newly discovered planet DQ. Its peculiarities promise to be suggestive at least in respect to questions of planetary origin in which geologists are concerned almost equally with astronomers. The new planet breaks across that rather forcefully deduced law of symmetry which has been thought to prevail throughout the solar system and which has been somewhat too influential perhaps in controlling hypotheses of its origin. The little stranger pays no respect to Bode's law, and is eccentric in other particulars. Its mean position lies between the earth and Mars, and its period of revolution is 645 days, while that of Mars is 687. Its orbit, however, is so eccentric that in aphelion the planet's path lies far outside of the Martian orbit in the zone of the asteroids, while in perihelion it passes within fourteen million miles of the earth, according to the provisional computations made from the earlier observations. One of the most interesting features of the new planet lies in the fact that its velocity at perihelion is greater than that of the earth, although it is farther from the sun. Should the two orbits be brought into coincidence by a suitable perturbation and a collision ensue, the velocity of the outer body would be the greater, at the moment of collision, though on the average it would necessarily be less. The effect of such a collision on the rotation of the earth would depend upon the particular point at which the stroke of the smaller planet was dealt. The probabilities, however, are in favor of a stroke which would accelerate the present *direct* rotation of the earth, or which would, if the earth had no rotation, impart to it a rotation in the same direction as that which it now possesses. It has been urged that meteoroidal bodies revolving in a ring around the sun would, on

union by collision, give rise to *retrograde* rotations, because the orbital velocities of the inner bodies are the greater, and this has been regarded as a serious objection to the aggregation of the earth and all but the outermost planets from a ring of discrete matter of the type of the Saturnian rings as distinguished from an aggregation from a gaseous ring after the manner of the Laplăcean hypothesis. (Faye, *Sur l'Origine du Monde*, 1896, pp. 165, 270–281). The writer has, however, pointed out that, if the aggregation of such discrete matter took place through the development of eccentric orbits which cut each other's paths and thus led to collision, the bodies pursuing the outer orbits would be moving faster *at the points of collision* than those pursuing the inner orbits, and that on the average the rotations resulting from the collisions would be direct (A group of Hypotheses Bearing on Climatic Changes, JOURNAL OF GEOLOGY, Vol. V, No. 7, 1897, p. 668). The new planet furnishes us with a concrete illustration of the principle urged. It has been estimated that, at the time of its greatest approximation, the new planet will be moving 500 feet per second faster than the earth, a figure which is doubtless subject to considerable correction from fuller data. The discovery of this rather erratic body has renewed the previous suggestion that small planetoids may not be rare in other tracts than the asteroidal belt between Mars and Jupiter. It will doubtless have some influence in reopening for renewed consideration the mode of aggregation and the past history of the solar system, a consideration which has been rendered opportune by the serious, if not fatal, objections to the accepted gaseous hypothesis which have arisen from the application of the kinetic theory of gases. T. C. C.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.[1]

Van Hise,[2] Bayley, and Smyth map and describe[3] the geology of the Marquette iron-bearing district of Michigan. The pre-Cambrian rocks of the district comprise three series, separated by unconformities. These are the Basement Complex or Archean, the Lower Marquette, and the Upper Marquette, the two latter constituting the Algonkian for this district. All of these are cut by basic intrusives. The pre-Cambrian rocks are unconformably overlain by Cambrian sandstone.

The Basement Complex occurs in two main areas, one north of the Marquette series, called the Northern Complex, and one south of the Marquette series, called the Southern Complex. There are also isolated areas within the Algonkian. The oldest rocks of the Basement Complex are thoroughly crystalline, foliated schists and gneisses. A close field and laboratory study has failed to detect in them any evidence of sedimentary origin. These gneisses and schists have been cut by various igneous rocks at different epochs. The latter occur both in the form of great bosses and in dikes, sometimes cutting, sometimes parallel to, the foliation of the rocks. In the area of the Northern Complex there have been volcanic outbursts, and a vast series of lavas, agglomerates, greenstone-conglomerates, and tuffs have been piled up. By far the greater part of the volcanic material is of an intermediate or basic character.

The Northern Complex is treated under the divisions of Mona schists, Kitchi schists, gneissoid granites, hornblende-syenites, basic dikes, acid dikes, peridotite, and ferruginous veins. The Mona and Kitchi schists are greenstone-schists, which are believed to be largely

[1] Continued from page 541, Vol. VI., this JOURNAL.

[2] The Marquette iron-bearing district of Michigan, by C. R. VAN HISE and W. S. BAYLEY; with a chapter on the Republic Trough by H. L. SMYTH: Mon. U. S. Geol. Surv. No. 28, 1896, pp. 1–607. With atlas of 39 plates. Preliminary report on same district, published in the 15th Ann. Report U. S. G. S., 1895, pp. 477–650.

[3] The Algonkian rocks are described by VAN HISE; the Basement Complex and later igneous rocks are described by BAYLEY; the Republic Trough is described by SMYTH.

recrystallized volcanic materials. Their original forms included both tuffs and lavas. The gneissoid granites and syenites are plutonic intrusive rocks within the greenstone-schists. The basic dikes are mainly diabase. The peridotite is older than the Cambrian sandstone and younger than the greenstone-schists of the Basement Complex. The ferruginous veins are believed to be water-deposited, and were formed previous to the deposition of the Lower Marquette series.

The Southern Complex differs from the Northern Complex in the smaller quantity of greenstone-schists in the former and in the presence in it of the micaceous and hornblendic schists, and the Palmer gneiss. It is treated under the divisions micaceous schists, amphibole-schists, gneissoid granites, Palmer gneiss, and intrusives. The micaceous schists include muscovite-schists, biotite-schists, feldspathic biotite-schists, and hornblendic biotite-schists. They are thought to be mashed acid eruptives. The amphibole-schists include greenstone-schists, hornblende-schists, and micaceous hornblende-schists. They are shown to be mashed basic eruptives. The granites and dike materials are similar in their essential features to the corresponding rocks of the Northern Complex. The granites are younger than the schists, since dikes from them intrude the schists. The Palmer gneisses occur only on the borders of the granite areas, between these and the Marquette sedimentaries, and are apparently in most cases extremely mashed phases of the granites.

The isolated areas of the Fundamental Complex within the Algonkian are chiefly gneissoid granites and schistose greenstones, that differ in no essential respect from the corresponding rocks of the Northern Complex and Southern Complex.

The Lower Marquette series is composed of the following formations, given from the base upward: The Mesnard quartzite, the Kona dolomite, the Wewe slate, the Ajibik quartzite, the Siamo slate, and the Negaunee iron formation. There is no break between these formations; the series is a continuous one.

The Mesnard quartzite is chiefly a metamorphosed sandstone. However, at the bottom of this formation is a conglomerate, which in grading into the sandstone passes through slate and graywacke. The conglomerate is basal, being composed of detritus from the Basement Complex. At the top of the formation is a slate. The Mesnard quartzite is the first deposit of the westward transgressing Lower Marquette sea. By the time the sea had advanced westward a short

distance upon the Marquette district, the Kona dolomite began to be formed, and hence the Mesnard formation is confined to the eastern part of the district. The thickness of the Mesnard quartzite is from 150 to 670 feet.

The Kona dolomite is largely an altered limestone, but it includes interstratified layers of slate, graywacke, and quartzite, with gradation phases between these and the pure dolomite. The Kona dolomite, like the Mesnard quartzite, is confined to the eastern part of the district. The dolomite varies through a slate into the Mesnard quartzite below, and by a lessening of the calcareous constituent gradually passes into the Wewe slate above. The thickness is from 425 to 1375 feet.

The Wewe slate is chiefly a metamorphosed mudstone, but with the slates are conglomerates, quartzites, graywackes, mica-slates, and mica-schists. The Wewe slate, like the two previous formations, is confined to the eastern part of the district. The formation grades into the Kona dolomite below and the Ajibik quartzite above. The thickness is from 550 to 1050 feet.

The Ajibik quartzite, is mainly a metamorphosed sandstone, which in different parts of the district, depending upon various conditions, has been transformed into quartzite, cherty quartzite, ferruginous quartzite, ferruginous cherty quartzite, quartz-rock, and quartzite-breccia. The time of the Ajibik quartzite marks a rapid advance to the west of the Lower Marquette sea, and therefore the formation extends to the western end of the district. In the eastern part of the area the Ajibik quartzite grades down into the Wewe slate, but for the major part of the district it rests unconformably upon the Basement Complex. At many localities contacts and basal conglomerates are known. The Ajibik quartzite grades above either into the Siamo slate or into the Negaunee iron formation. The thickness is from 700 to 900 feet.

The Siamo slate is chiefly an altered mudstone, although locally it is a graywacke or quartzite. The larger area of exposure of the formation is confined to the eastern part of the district, although a belt of the formation runs near the north side of the Marquette series to the west end of the district. The Siamo slate grades into the Ajibik quartzite below and into the Negaunee iron formation above. The thickness is from 600 to 1200 feet.

The Negaunee iron formation is nonfragmental, heavily ferruginous

throughout, and contains the greater iron ore deposits of the district. The formation comprises sideritic slate, which may be grüneritic, magnetitic, hematitic, or limonitic; grünerite-magnetite-schist; ferruginous slate; ferruginous chert; jaspilite, and iron ore. Large quantities of intrusive greenstones are associated with the formation, the masses of which vary in magnitude from great bosses two miles or more long and a half mile wide to small dikes. The largest area of the Negaunee formation is in the east-central part of the district. From this area two belts extend west to the western end of the district. Upon the whole the formation is soft, and occupies lowlands between the more resistant greenstones and the Ajibik quartzites. The formation is underlain by the Siamo slate or Ajibik quartzite, into which it grades, and is overlain unconformably by the Upper Marquette series.

The sideritic slate is the original form from which the other varieties of rock have developed. The grünerite-magnetite-schists were formed by partial recrystallization of the silica, by oxidation of the iron oxide in part to magnetite, by a union of a part of the silica and iron protoxide, producing grünerite, and with the loss of carbon dioxide. The ferruginous slates are the direct result of the decomposition of the iron carbonate and the peroxidation of the iron, with partial or complete recrystallization of the silica. The ferruginous cherts differ from the ferruginous slates in that the iron oxide and the chert are largely concentrated into alternate bands. The jaspilites differ from the ferruginous cherts in that each of the quartz grains of the chert bands is stained red by included hematite. The iron ores resulted from the concentration of the iron oxides through the agency of downward-percolating waters. These concentration-bodies usually occur upon impervious basements in pitching troughs. The pitching troughs are formed by the Siamo slate, the Ajibik quartzite, a mass or dike of greenstone, or by some combination of these. The ore deposits are likely to be of large size where, as a result of the folding, the iron-bearing formation is much fractured, thus permitting the ready access of percolating waters. The ore deposits occur at the bottom of the Negaunee formation, within the Negaunee formation, and at the contact horizon between the Negaunee formation and the overlying Ishpeming formation. From the position of the ore deposits above the impervious formations, it is concluded that their concentration occurred during or subsequent to the folding which took place later than Upper Marquette time.

The Upper Marquette series is composed of the following formations, from the base upward: The Ishpeming formation, the Michigamme formation, and the Clarksburg formation, in conformable succession.

The Ishpeming formation includes two classes of rocks, which are called the Goodrich quartzite and the Bijiki schist. These rocks are sufficiently different to have different formation names, but the Bijiki schist for the west end of the district occupies a part of the horizon of the Goodrich quartzite in the central part.

The Goodrich quartzite includes quartzites, micaceous quartz-schists, mica-schists, mica-gneisses, and at the base a basal conglomerate. For the major part of the district this conglomerate rests upon the Negaunee formation, and the rock is an ore, chert, jasper, and quartz conglomerate. At a few places the Archean rocks are subjacent, and here their materials predominate in the conglomerate. The Goodrich quartzite is confined to the central and western parts of the district. For the major part of the district it rests unconformably upon the Negaunee formation. In places erosion has cut through the Negaunee formation into the Ajibik quartzite, and in a few cases even to the Archean, and here the Goodrich quartzite may be found resting on the lower formations. For the greater part of the area the Goodrich quartzite grades up into the Michigamme or Clarksburg formation, but in the northwestern part of the district it passes up into the Bijiki schist. The thickness is from 600 to 1550 feet.

The Bijiki schist is a banded grünerite-magnetite-schist, which has been derived by metasomatic and dynamic processes from an impure siderite. It is confined to the western part of the district. The Bijiki schist grades into the Goodrich quartzite below and into the Michigamme formation above. The thickness is from zero to 520 feet.

The Michigamme formation includes slates, graywackes, mica-schists, and mica-gneisses. The formation is exposed in a single large belt, running from the center to the western end of the district. It grades below into the Goodrich quartzite, Bijiki-schist, or Clarksburg formation. The thickness cannot be accurately estimated, but it is probably as much as 2000 feet.

The Clarksburg formation is composed predominantly of volcanic materials, embracing basic lava flows, tuffs, ashes, and breccias, which locally are interleaved with or grade into slate, graywacke, or conglom-

erate. Much of the material has been profoundly metamorphosed, and schist-conglomerates, mica-schists, and hornblende-schists have resulted. All of these rocks are cut by dikes and masses of greenstone. The formation is confined to the south central part of the district. The volcanic material was poured out from the number of vents, the more important ones which have been recognized being located near Clarksburg, Greenwood, and Champion. The formation grades into the Ishpeming formation or the Michigamme formation below, and into the Michigamme formation above. The Clarksburg formation belongs in age, either between the Goodrich quartzite and the Michigamme formation, or near the base of the latter. No estimate of the thickness can be given.

The igneous rocks, other than those of the Clarksburg formation, are divided for convenience in discussion into two classes, in the first of which are placed those associated exclusively with the beds below the Clarksburg formation, and, in the other, those cutting also the beds above the Clarksburg. The rocks are all basic. The older rocks occur as dikes, bosses, sheets, and tuff beds, although the latter two are subordinate. The post-Clarksburg greenstones comprise only dikes and bosses. It is conjectured that these later greenstones may be the equivalents of some of the Keweenawan eruptives.

Evidence of the unconformity between the Lower Marquette series and the Basement Complex is clear and abundant. At numerous places in the district the actual contacts of the basal conglomerate of the Marquette series and the Fundamental Complex may be seen. In all of these cases the detritus is most distinctly waterworn, and, while the major part of the material in each case has been derived from the immediately subjacent part of the Basement Complex, other material not occurring in the immediate neighborhood is found, thus showing conclusively that these rocks are not reibungs or fault breccias. There may be mentioned the principal localities at which contacts are well exposed.

At the east end of the south side of the Marquette district there are several localities, from Lake Superior to west of Lake Mary, where a conglomerate is found bearing numerous bowlders of granite, gneiss and schist, identical with the rocks constituting the Basement Complex immediately adjacent. In Secs. 22 and 23, T 47 N, R 26 W, are two islands of the Basement Complex, about which are found magnificent exposures of great bowlder-conglomerate and recomposed granite,

resting with visible contact upon the Basement Complex, and composed of material mainly derived from it. South of the Cascade range, there are again a number of localities from Secs. 34 to 32, T 47 N, R 26 W, where there are basal conglomerates, the great bowlders again being mainly identical with the adjacent granites, gneisses, and schists of the Basement Complex. South of Summit Mountain, in the west half of Sec. 25, T 47 N, R 27 W, is an exposure of the basal conglomerate. The conglomerate grades downward into a schist which is scarcely distinguishable from the Palmer gneiss, with which it is in contact. The next contact to the west is in Sec. 28, T 47 N, R 27 W, where the phenomena are similar to those south of Summit Mountain. At the end of the Republic Trough a conglomerate hangs with visible contact upon the flank of the Archean granite, bearing well rounded waterworn bowlders from it.

At the north side of the Lower Marquette series, and near the east end of the district there is exposed a magnificent basal conglomerate about three miles west of Marquette, north of Mud Lake. The next contacts to the west are at the base of the quartzite east and west of Teal Lake. At one place here the relations are such that the layers of the conglomerate cut across the foliation of the subjacent schists at an acute angle. Still farther west, in Sec. 30, T 48 N, R 28 W, contacts are found in a number of places. West of this point the only actual contact known is north of the Michigamme mine.

The unconformity between the Lower Marquette and Upper Marquette series is also well marked. At the close of Lower Marquette time the land was raised above the sea, gently folded and eroded, and the Upper Marquette sediments were later laid down unconformably upon this floor. In general the discordance between the Lower Marquette series and the succeeding series is not great, being measured frequently by five to ten degrees, at other times by ten to fifteen degrees, and it is only rarely that the plications of the lower series are such as to make the beds abut perpendicularly against those of the overlying series. Erosion has cut deeper in the Lower Marquette series in some places than in others, so that the Upper Marquette series rests upon different members of the lower series. At the east end of the area it left a very considerable thickness of the iron-bearing formation, but in places to the west this formation is quite cut out. Indeed, in places erosion cut through the Siamo slate and the Ajibik quartzite, and in some places even into the Basement Complex. This

particularly occurs in the west and southwest parts of the district, west of Champion and along the Republic Trough, where but few members of the Lower Marquette series were deposited. Even within a short distance the differential erosion was considerable. For instance, at the south end of the Republic Trough the variation was more than 1500 feet.

The Marquette district has been folded in a complex manner. The largest but least conspicuous fold of the district is an anticline having a north-south axis, running through the city of Marquette. This great fold has, especially near its crown—that is, for the eastern six or eight miles of the district—folds of the second order superimposed upon it, making this part of the fold an anticlinorium. The other major anticline belonging to this system of folds is one running north and south through the east end of Michigamme Lake. The major part of the district has been affected, however, by much more effective pressure in a north-south direction, so that the folds in an east-west direction are much more conspicuous than the north-south folds of greater wavelength and greater amplitude. As a result of the north-south pressure, the Upper and Lower Marquette series together have been bent into a great abnormal synclinorium. This synclinorium is of a peculiar and complicated character. The Algonkian rocks on either side of the trough have moved over the more rigid Archean granite, and, as a consequence, on each side of the Algonkian trough a series of overfolds plunge steeply toward its center, producing a structure resembling in this respect the composed fan structure of the Alps. There is, however, this great difference between the Marquette structure and that of the Alps, that in passing from the sides of the trough toward the center, newer rocks appear rather than older ones, so that in the center of the synclinorium the youngest rocks are found. It is as if the composed fan folds of the Alps were sagged downward, so that the structure as a whole is a synclinorium rather than an anticlinorium. This form of folding has been elsewhere defined by Van Hise[1] as an abnormal synclinorium. The folding is closer in the western part of the district than to the east. The strikes of most of the exposures of the district are mainly controlled by the east-west folds, but, at the east and west ends of the areas of the formations, the larger north-south folds already described control.

[1] Principles of North American Pre-Cambrian geology, by C. R. VAN HISE, 16th Annual Report U. S. Geol Surv., Part I, 1896, p. 612.

The rocks of the district have yielded to the folding in different ways. Where brittle the close plications have resulted in their being fractured through and through, and in many places they pass into reibungsbreccias. These phenomena are particularly prevalent in the Negaunee iron formation and in the quartzites. The more plastic formations have yielded without major fracturing, but in a minor way they show everywhere the effects of deformation. A microscopical study shows that not a cubic inch of material has escaped dynamic action. While, as a further consequence of dynamic action there has been local faulting at various places, with two or three exceptions, no important faults have been observed in this district.

Because of the varying strength and texture of the various beds and formations, the readjustments necessary in folding took place in large measure between the different formations and between dissimilar beds of each formation. As these layers were rubbed over one another, schistosity was developed parallel to the bedding in many places. The unconformable contacts between the Upper Marquette and Lower Marquette series, and between the Archean and Lower Marquette series, were the greatest planes of movement, and adjacent to them the rocks of both the series were rendered schistose. In the nearly homogeneous Michigamme and other slates there apparently occurred an actual flowage. Here there is frequently a discordance between the cleavage or schistosity and the bedding.

It is inferred from the phenomena of deformation that, when folded, the rocks which are now at the surface were buried under a thickness of several thousand feet of sediments, not impossibly as much as ten thousand feet. On the other hand, it appears that the formations were not so deeply buried as to be beyond the sustaining strength of strong rocks like quartzites, or else the layers of these rocks would have been folded without the production of reibungsbreccias, as in the case of the Doe River quartzite of Tennessee.

As shown by the above facts, the Marquette district furnishes a beautiful instance of deformation in the lower part of the zone of combined fracture and flowage.[1]

The Lower Marquette and Upper Marquette series are correlated with the Lower Huronian and Upper Huronian series of the north shore of Lake Huron. The reasons are stated in previous publica-

[1] Principles of North American Pre-Cambrian geology, by C. R. VAN HISE. 16th Annual Report U. S. Geol. Surv., Part I, 1896, pp. 601–603.

tions, and are not repeated.[1] The succession in the Menominee district of Michigan, as given by Smyth,[2] is compared with that of the Marquette district, and points of similarity and difference noted. It is shown that the series of the two districts may be roughly correlated, but that closer correlation may not be attempted until more detailed studies are made in the Menominee district.

Newett[3] gives a sketch of the Marquette iron-bearing district of Michigan, and publishes a geological map of the district compiled from a map of the Upper Peninsula in the possession of the Michigan Geological Survey. The iron ores occur in the Huronian rocks, of which there are some thirty members. This series of rocks has been subjected to enormous lateral pressure, resulting in foldings in the strata. In the folds the ore is found generally in lenticular masses. The Huronian rocks are cut by eruptive rocks, which have played an important part in assisting in the concentration of the ores.

Gresley[4] describes peculiar markings in iron ore from the Chapin mine of Iron Mountain, Mich., which are thought by H. S. Williams, by Schuchert and by Walcott to be trails of organic origin.

Comments.—At various places in the Menominee district, including the Chapin mine, the Cambrian sandstone unconformably overlies the ferruginous schists of the Huronian. At some localities the lowest horizon of the Cambrian is an iron ore, which has been mined. The question arises whether or not the organic remains referred to by Gresley are contained in the original ore of the Huronian or in the detrital ore of the Cambrian. As the specimens were found in the ore after it had been shipped from the district, it seems impracticable to answer this question, and therefore it is unsafe to conclude that the organic markings are of pre-Cambrian age.

[1] Correlation papers—Archean and Algonkian, by C. R. VAN HISE. Bull. U. S. Geol. Surv., No. 86, 1896, pp. 183–186.

Principles, cit., pp. 796–799.

[2] The Lower Menominee and Lower Marquette series in Michigan, by H. L. SMYTH. Am. Jour. Sci., 3d series, Vol. XLVII, 1894, pp. 216–223.

[3] The Marquette Iron Range of Michigan, by G. A. NEWETT. Proc. Lake Superior Mining Inst., Vol. III, 1895, pp. 87–108. With geol. map.

[4] Organic markings in Lake Superior iron ores, by W. S. GRESLEY. Science, new series, Vol. III, 1896, pp. 622–623.

Van Hise[1] describes baselevels in the crystalline rocks of central Wisconsin and Keweenaw Point. In the Wisconsin district the Archean and Huronian rocks occupying the area are truncated to an even baselevel with an apparent southerly slope. The altitude is about 1450 feet.

On Keweenaw Point the peaks of the main trap range rise to so nearly the same altitude that they form an apparent plain, which is considered an ancient baselevel. The altitude of this plain is about 1350 feet. Certain peaks, consisting of hard quartz-porphyry and felsite, have resisted weathering, and stand above this plain.

The central Wisconsin plain has not been so deeply dissected as the Keweenaw Point area, but this is explained by the fact that it is not so near either of the great lakes, and therefore erosion has not been so effective over it.

From the proximity of the central Wisconsin and Keweenaw Point baselevels, and from the fact that they have nearly the same altitude, it is concluded that the baselevels of the two districts are probably but parts of a far more extensive baseleveled region resulting principally from the subaërial erosion of Cretaceous time, and perhaps also, in part, from the marine denudation of the Cretaceous.

Hubbard[2] describes the relation of the copper vein at the Central mine, Keweenaw Point, to the Kearsarge conglomerate. The veins of Keweenaw Point belong largely to one system, and are confined principally between T 57 N, R 32 W, and the northeast extremity of the Point. The copper-bearing formation between these limits dips N 33° E, at the first locality, to south of east at the last, and the veins are nearly at right angles to the formation. The Central mine is situated in Sec. 23, T 58 N, R 31 W, about eighteen miles northeast of Calumet. Here there has been a northerly sliding of the formations above the Kearsarge conglomerate, as a result of which the copper vein in the overlying formations is found to stop abruptly at the Kearsarge conglomerate. In this mine is the eastern edge of the basin in which the Kearsarge conglomerate was deposited.

[1] C. R. VAN HISE, A central Wisconsin baselevel, Science, Vol. IV, 1896, pp. 57–59; A northern Michigan baselevel, *ibid.*, pp. 217–220.

[2] The relation of the vein at the Central mine, Keweenaw Point, to the Kearsarge conglomerate, by L. L. HUBBARD, Proc. Lake Superior Mining Inst., Vol. III, 1895, pp. 74–83.

Winchell, H. V.,[1] gives a brief sketch of the iron ranges of Minnesota. Along the north side of the Mesabi range is a ridge of Archean syenite and granite, flanked on both sides by crystalline and semi-crystalline schists. This ridge is called the Giant's Range. On the south side of the Giant's Range, lying at times nearly up to its summit, are the outcropping edges of Taconic or Upper Huronian strata, which overlie unconformably the syenites and schists. These are in turn overlapped to the south by eruptive rocks of Keweenawan age and by Cretaceous sediments. The ore is soft hematite, which lies at low angles from the horizontal, usually covered merely by drift.

The geology of the Vermilion Range is not yet understood. The iron ores are solid and massive, except at the Chandler mine, where they are brecciated, and occur in steeply inclined lenses between walls of schist, extending to an indefinite depth.

Lawson[2] describes a family of basic plutonic orthoclase rocks rich in alkalies and lime, which he names malignite, as occurring in the form of a laccolite in the Coutchiching schists of Poohbah Lake. The malignites vary from basic nepheline-pyroxene malignite through garnet-pyroxene malignite to amphibole malignite.

Coleman[3] makes a second report on the gold fields of western Ontario, including the area between Finmark, near Thunder Bay, and the Manitoba boundary, and between Minnesota and Keewatin on the north shore of Lonely Lake. This visit confirms his impressions of the geology of the area as given in the preceding report of the bureau.[4]

At many places the Laurentian rocks show an eruptive contact with the overlying rocks, showing that they must have been consolidated later than the Huronian. Coleman suggests that it would be more logical to confine the name *Laurentian* to the oldest complex of thoroughly crystalline rocks serving as a foundation for all succeeding rocks, and to describe the clearly eruptive rocks which penetrate the

[1] The iron ranges of Minnesota, by H. V. WINCHELL, Proc. Lake Superior Mining Inst., Vol. III, 1895, pp. 11–32.

[2] Malignite, a family of basic plutonic orthoclase rocks rich in alkalies and lime, by ANDREW C. LAWSON, Bull. Dept. of Geol., Univ. of Cal., Vol. I, 1896, pp. 337–362, Pl. 18.

[3] A second report on the gold fields of western Ontario, by A. P. COLEMAN, Fifth Rept. Bureau of Mines, Ontaria, for 1895, Sec. II, pp. 47–106, 1896.

[4] Reviewed in this JOURNAL, Vol. IV, pp. 744–745.

overlying Huronian schists as eruptives, of later age than at least the earlier members of the Huronian. If this were done, very little of the territory under consideration could be mapped as Laurentian —perhaps none of it with certainty. However, the discrimination may not be made until more detailed work has been done in the district.

Coutchiching mica-schists and gneisses, though probably present, have not been certainly recognized. The series of eruptives, pyroclastics, and less common waterworn clastics, Lawson's Keewatin, is of widespread occurrence, and of great importance as containing the gold-bearing veins of the district. It is spoken of under the general term Huronian.

Blue[1] sketches the geological history of the New Ontario, which includes that part of the province of Ontario lying beyond the Matawan and French rivers, and the Nipissing, Huron, and Superior lakes, to the north and west boundaries of the province. Laurentian and Huronian rocks form highlands which in Archean time were the most important physical feature of North America, sweeping in a curve through what is known in our time as the regions of Labrador, Quebec, Ontario, and the Northwest Territories. While there are large areas in which eruptive masses of granite and gneiss have penetrated the Huronian rocks, and thrown them into folds, proving their later age, in general the reverse is the case, the Huronian resting unconformably upon the Laurentian, and being of later origin. The Huronian is overlain unconformably by Cambrian rocks, under the Cambrian being included Animikie, Nipigon, and Potsdam rocks.

Comments.—The term *Cambrian*, as here used, covers Animikie, Keweenawan, and Potsdam rocks. The two former have ordinarily been regarded as pre-Cambrian.

Dowling[2] reports on the geology of the country in the vicinity of Red Lake and part of the basin of Berens River, in the district of Keewatin, Canada. The rocks exposed are all Archean, including gneisses

[1] The New Ontario, by ARCHIBALD BLUE. Fifth Rept. Bureau of Mines, Ontario, for 1895, pp. 193–196, 1896.

[2] Report on the country in the vicinity of Red Lake, and part of the basin of the Berens River, District of Keewatin, by D. B. DOWLING, Ann. Rept. Geol. Surv. of Canada, for 1894, Vol. VII, Part F, 1896, pp. 54. With geological map.

and granites classed as Laurentian, and folded schists and greenstones classed as Huronian.

The Laurentian rocks prevail over a much greater area than the Huronian rocks, being seen along the White and Berens rivers, on Lac Seul, and on the English and Matawan rivers. They are gneisses and granites, the latter in places apparently intrusive in the former, as along the headwaters of the Berens River. The granites are occasionally intrusive also in the Huronian to the south.

The Huronian rocks are a series of schists, limestones, and water-deposited volcanic materials. They occur in two main areas. The eastern one is in the vicinity of Clearwater and Woman lakes. The eastern boundary of this area has not been defined; to the west, the Huronian is in contact with the Laurentian. From the southwestern part of the area, a belt extends southwest to the vicinity of Shallow Lake. The western area of Huronian occurs in the vicinity of Red Lake, and is surrounded by and incloses areas of Laurentian granite and gneiss.

Contacts of the Laurentian and Huronian rocks are described for numerous localities. The contacts are "generally of a brecciated character, the gneisses and granites while in a plastic condition surrounding and inclosing the Huronian schists" (p. 40).

The Huronian rocks are similar in many respects to the Keewatin series of the Lake of the Woods and Rainy Lake districts, to the south: but the Huronian of the area under discussion includes dark blue limestone, and conglomerates with jasper pebbles, both very similar to those of the typical Huronian area north of Lake Huron, and the rocks are accordingly mapped as Huronian.

The Coutchiching, supposed by Lawson to underlie the Keewatin of the Rainy Lake country, is possibly here represented by a small area west of Shallow Lake, mapped as Huronian. However, at Gull Rock Lake, rocks which still more resemble the Coutchiching of the Rainy Lake region are found to be but highly altered Huronian beds in contact with the Laurentian, which, when followed along the strike, take on the general aspect of the remainder of the Huronian of the district.

GENERAL COMMENTS.

In the articles by Blue, Coleman, and Dowling the term *Laurentian* is used to cover both the ancient basement upon which the Huronian rocks were deposited, and later granitic intrusives, although Coleman

recognizes the fact that the logical course is to confine the term Laurentian to the older rocks. This usage of the term is a serious obstacle to the progress of structural geology in this region, for two entirely different series of rocks are confused. Plainly the rocks called Laurentian upon which the Huronian was deposited are pre-Huronian; it is equally certain that the granites called Laurentian which cut the Huronian are Huronian or post-Huronian in age. So long as these two classes of rocks are confused on the maps, no such thing as a structural map of the area northwest of Lake Superior is possible.

C. K. Leith.

Reviews.

Elemente der Gesteinslehre. By H. Rosenbusch, Stuttgart, 1898.

That this book presents the essential features of Professor Rosenbusch's lectures on petrology as they have been developed during thirty years of his experience, is sufficient guarantee that the work is a most valuable contribution to the didactic side of the subject. That those who are not permitted to listen to Professor Rosenbusch in Heidelberg may read his careful presentation of the essential characteristics of rocks is fortunate, and the appearance of the book so long looked for is a fact upon which many may congratulate themselves. No satisfactory review of a work so full of matter can be given without close and exhaustive reading, but some insight into its character may be gotten without exhausting the subject.

In attempting to condense the wide range of facts and speculations relating to igneous, sedimentary and metamorphosed rocks into the space of an elementary text-book, minor details and qualifications of statements are minimized or omitted, thereby sharpening the outlines of the images presented to the mind. As a necessary result we find in some cases positive statements where we should expect tentative ones, and a tone of finality in portions of the work where we had not expected it. This is of course noticeable in the introductory portions of the parts devoted to the three categories of rocks.

The general introductory chapter, after defining a rock, and the scope of petrology, treats of the methods of investigating rocks, geologically, mineralogically and chemically, special attention being given to the chemical characteristics. Definitions of the principal terms used in connection with the mineral constituents are followed by an account of varieties of parting and jointing of rocks and a brief statement of their formation and classification.

Part I deals with eruptive rocks, first considering their constituents as chemical compounds and as minerals, and the relation of the latter to one another both as to the order of their crystallization and as to their morphology. Then their geological characteristics are described.

Considerable space is given to their texture or structure, with special reference to their interpretation in terms of the occurrence of the rocks and the order of crystallization of the mineral constituents. The age of igneous rocks and their alteration and metamorphism are briefly treated, and a system of classification is given without discussion of the principles on which it is based. The classification followed is the same as that employed in Professor Rosenbusch's work on the Microscopical Physiography of the Massive Rocks, with slight modification in the divisions embracing "*Tiefengesteine*" and "*Ganggesteine.*" An age distinction has disappeared from the grouping of "*Ergussgesteine,*" so that liparite and quartz-porphyry are described together.

The description of each class of rocks embraces the mineralogical and microscopical characteristics, besides the chemical composition, which is shown in ample tables of analyses both of the rocks as a whole and of separate mineral constituents. This feature is a very marked addition to the treatment of the subject in the Microscopical Physiography of Massive Rocks. The metamorphism of igneous rocks themselves and that produced by them upon adjacent rocks is described in immediate connection with the description of the unaltered rocks.

The part devoted to stratified rocks follows the same general plan as Part I. The rocks are classified under the heads of: precipitates, psephites and psammites, silica rocks (not previously described), carbonate rocks, iron rocks, clay rocks, porphyroids and fossil fuels. In this part also, considerable is introduced that belongs to the subject of metamorphism.

Part III treats of the crystalline schists, their composition, geological occurrence, texture and classification. Crystalline schists are said to be eruptive or sedimentary rocks that have attained geological transformation chiefly through the coöperation of geo-dynamic agencies. The classification of these rocks is that commonly used and the author recognizes its artificial and unsatisfactory character but considers our knowledge and judgment in the matter not yet sufficiently advanced to warrant any attempt at its betterment at this time. The order followed is: gneisses, mica-schists, talc-schists, chlorite-schists, amphibole and pyroxene rocks, serpentine, rocks of the lime series, magnesia series, iron series, and emery (corundum). In each class the mineral and chemical compositions are described together with the texture and the varieties of rock embraced within each class.

Whatever may be our view of the position taken by Professor Rosenbusch upon certain mooted questions in petrology, we must acknowledge the great value of this recent work, and congratulate the author upon its publication. J. P. I.

A Text Book of Mineralogy with an extended treatise on Crystallography and Physical Mineralogy, by E. S. DANA, New York, John Wiley & Sons, 1898.

This is a new edition of Professor Dana's former text-book entirely rewritten and enlarged. It consists of four parts devoted to crystallography, physical mineralogy, chemical mineralogy, and descriptive mineralogy, and contains an appendix treating of the drawing of crystal figures, and of projections, besides one giving tables to be used in the determination of minerals.

The relation of crystal form to other physical properties and to the probable molecular structure of crystals is set forth in the introductory paragraphs of Part I, and the grouping of the crystal forms is made in relation to the thirty-two classes of symmetry. For this reason it would seem that a more logical arrangement of the subject would place the physical mineralogy first and the crystallography afterwards.

The arrangement of the types of crystal forms although referred to the classes of symmetry is the order usually employed in elementary treatises, namely, the group with the most complex symmetry first. The necessity for this order of arrangement is questionable.

The treatment of the six crystallographic systems is quite full and in addition to the description of the symmetry and principal forms are given their spherical projection and the mathematical relations of each system. Compound or twin crystals and the irregularities of crystals are described at length and are profusely illustrated.

The physical characters of minerals are treated briefly in connection with those of cohesion, elasticity, and relative density, as well as those related to heat, electricity, and magnetism. The optical properties are considered at greater length, both as to the principles involved and their application to the optical investigation of minerals. In this respect the improvement over former editions of the Text Book is marked. The part devoted to chemical mineralogy includes a statement of the general principles of chemistry which apply to minerals

and a brief description of methods of chemical examinations of minerals.

The descriptive mineralogy is an abridgment of the sixth edition of Professor Dana's System of Mineralogy and possesses most of the advantageous features of the larger work. However, much of the material of the latter work is necessarily excluded from a text-book.

Perhaps the most striking feature of the new edition of this Text Book of Mineralogy is the condensation of the material, a great amount of information being compassed by so few pages. Its adaptability for class instruction, however, has yet to be tested, and it is hoped that it will prove satisfactory. Its need has been long felt and Professor Dana is to be thanked for its preparation. It is regrettable that the figures used for illustration vary so greatly in merit. While most of them are excellent, some are quite defective or are poorly printed so that the lettering is obscure or the edges of crystals confused.

J. P. I.

Manual of Determinative Mineralogy with an introduction on Blowpipe Analysis, by GEORGE J. BRUSH. Revised and enlarged, with entirely new tables for the identification of minerals, by Samuel L. Penfield. Fifteenth edition. John Wiley & Sons, New York. Chapman & Hall, London, 1898.

In 1896 a revision of the introductory chapters of this book, relating to blowpipe analysis and the chemical reactions of the elements, was published, and was reviewed in this JOURNAL, Vol. V, p. 86. The character of the work published at that time was of so high an order as to raise expectations regarding the promised revision of the tables for the identification of minerals. These expectations have been fully satisfied by the present publication. The advancement of mineralogical knowledge since the tables were first arranged in 1874 by Professor Brush has necessitated their expansion and rearrangement and has permitted of their being rounded out into more perfect form. The new tables are not only almost double the length of those published two years ago, but are more complete in the amount of data furnished under each mineral species. And, while the number of species of minerals in the new tables is much larger than formerly, the student is saved from confusion by the printing of the commoner kinds in stronger type than that used for the rarer ones. There are frequent

evidences of the care taken by the author to prevent errors on the part of the student, and, with the detailed methods of procedure described in the introductory chapters, it would seem as though everything had been done to enable the student to fit himself to identify minerals by all means except those based on their optical behavior in polarized light.

A chapter has been introduced into this edition treating of the crystal forms of minerals in a manner especially adapted to beginners. The treatment is necessarily brief as regards the principles of crystallography. Particular stress has been put upon the illustration of the subject. The number of figures is not only large as compared with the extent of the text, but care has been taken to employ examples most likely to be met with by the student, and the drawing of the figures has been well done. The method of treatment is mainly descriptive, and, though conceptions of symmetry are introduced, and excellent figures representing the relative positions of different axes of symmetry are given in connection with various subdivisions of crystal forms, the application of symmetry to the forms or its relation to them is left to the student to work out. The arrangement of the groups or systems of crystal forms is that ordinarily followed, beginning with those having the most complex symmetry, holohedral isometric crystals, and finishing with crystals without symmetry, the triclinic. Subdivisions of each of these systems are called normal, when holohedral according to former usage, and when having less symmetry than the highest in each system, that is, when belonging to what have been called hemihedral or tetartohedral, they are named after some characteristic crystal form or after some mineral characterized by such a form.

In all parts of the book there are evidences of the great care taken by the author to render the subject intelligible to persons taking up the study of minerals for the first time, and there can be no question as to the success of the endeavor. J. P. I.

The Lower Cretaceous Gryphæas of the Texas Region. By ROBERT THOMAS HILL and THOMAS WAYLAND VAUGHAN. Bulletin No. 151, U. S. G. S. Washington, D. C.

The bulletin presents a careful study of that group of fossil oysters which has generally been referred to *Gryphæa pitcheri* of Morton. The authors vigorously criticise the opinions and descriptions formerly

published, and dwell with laudable earnestness upon the confusion resulting from carelessness and from opinions based upon inadequate investigation. The great variability of the *Ostreidæ* is emphasized, but the authors correct the opinion previously held that this variability destroys their value in stratigraphy. They show that the hemeræ of many forms have well defined limits and are, therefore, of the greatest use in determining horizons. No classification yet given is satisfactory for the Texas *Ostreidæ.* The forms are tabulated provisionally under the old familiar names.

After this discussion, which deals in some measure with the family in general, the authors confine their attention to the specific object of the paper. The various forms which have been referred to *Gryphæa pitcheri* are discussed from a historical standpoint and their stratigraphic and geographic distribution noted. The species of the group are specifically defined and many data given regarding their development and methods of growth, and lastly, something of their phylogeny. A large part of the bulletin is taken up with plates showing the various species at different stages of growth and the individual shells in different positions. The figures formerly published are also reproduced for comparison. The work is especially commendable for careful investigation and clear-cut presentation. W. T. LEE.

Le Granit des Pyrénées et ses phénomènes de contact—Premier memoir: Les contacts de la Haute-Ariège, par M. A. LACROIX, Professeur de Minéralogie au Mus. d'Hist. Nat. Bull. des serv. de la carte géol. de la France. No. 64, tome X. Paris, 1898.

The area which has furnished the results published by M. Lacroix in this bulletin is situated in the very mountainous southern tract of the Departement of the Ariège, about 100^{km} southeast by south of the city of Toulouse. The Ariège, one of the head waters of the Garonne, flows through the region. Most emphasis is laid on the phenomena of contact exhibited on the right bank of the stream, since the exposures are considerably more accessible and continuous than on the left bank. The facts of observation on both banks are, however, accordant.

This, the first memoir on the granite massifs of the Pyrénèes, is devoted to a purely mineralogical treatment of igneous contacts, which

of itself cannot fail to impress the reader with a sense of the abundant store of facts from which M. Lacroix has drawn his interesting and even startling conclusions. These refer to the prime topics of exomorphic and endomorphic metamorphism and the *mise en place* of the granite, on all three of which the investigations of M. Lacroix shed new light.

The granite occurs in the form of a broad stock stretching some 50^{km} from east to west, and the bulletin refers particularly to the contacts at the western end. The rock is a normal coarse-grained granitite, sometimes, though never at the contacts, charged with phenocrysts of microcline several centimeters long. At the contacts it is filled with an extraordinary number of inclusions of the country rocks.

The latter are composed of slates and quartzites with non-magnesian limestones, either massive or interrupted with interbedded slaty layers. All of these rocks have been affected, often profoundly, by contact metamorphism. To this cause is to be attributed the development of a micaceous character, with garnet, cordierite, and sillimanite common in the contact belt. But the most important determination of this new crystallization is that of the existence of orthoclase and of the triclinic feldspars in the micaceous slate zone (*leptynolites*) in amounts which make the feldspar, either the predominant constituent or less abundant, even to its appearing only as scattering grains. This feldspathization has occurred by the process of "imbibition" or by the injection of minute granite apophyses *lit par lit*. The quartzites are similarly feldspathized and rendered micaceous, though in less marked degree than the slates. The white and black limestones, on the other hand, are much more affected, containing grossularite (*grenatite*), vesuvianite, various pyroxenes and amphiboles, epidote (*epidotite*), and the triclinic feldspars from oligoclase to anorthite (*Cornéennes feldspathiques*). Marmorosis is common. On p. 48, M. Lacroix has given a clear statement of the theory of feldspathization and of the part played by the *agents minéralisateurs* in the recrystallization of metamorphic belts. As is well known, he is at one with MM. Fouqué, Michel Lévy, Barrois and others who contend for an actual migration of granite substance from an intrusive granite stock in the presence of mineralizing agents, into the country rock, as well as for the possible removal of certain elements in the exomorphic contact zone under the same conditions of intrusion. A detailed argument for this position is given in Chapter III; its analysis would be beyond the scope of this review.

It is particularly in the study of endomorphic contact action that the bulletin demands the attention of petrographers. While the slates do not seem to have exerted any very pronounced effect on the granitite except in the way of slightly altering its structure, the limestone contact is one pronounced, both from the quality of the changes wrought and from their great areal extent, to be the most noteworthy phenomenon of the region. By the assimilation of the limestone, the granitite successively loses the alkaline feldspars, orthoclase, microcline and anorthoclase, and lastly, quartz, and gains other constituents rich in lime, the basic plagioclases and hornblende. The result is to produce a gradual replacement of the pure granitite magma in the massif by secondary mixtures which have crystallized out as hornblende-granitites, quartz-diorites, diorites, norites and hornblendites. Biotite and hornblende appear in the whole series. When, finally, olivine replaces all the feldspars, the resulting rock, though again the product of assimilation in the same way as the more acid rocks just enumerated, is an amphibole peridotite! The evidences for the fact of magmatic incorporation are exceptionally strong; they may be summarized as follows:

1. Field observations in connection with many localities of actual contact and the study of numerous thin sections showed ordinarily an insensible transition in mineralogical characters from the normal granitite to the basic types.

2. These hornblende rocks are developed only in zones of contact between typical granitite and the limestone, or else in bands which represent the prolongation of limestone layers stretching out into the granitite—a significant mode of occurrence emphasized in the memoir. Such basic bands, extending through the granitite from one end of an interrupted limestone layer along its strike to the corresponding end on the other side of the stock, are interpreted as being the product of recrystallization of mixed granite magma and digested limestone during a prolonged static condition of the igneous rock—that is, a period of quiescence as regards ascensional or lateral movement in the mass. It is hard to resist the conclusion that the map and numerous cross-sections of M. Lacroix prove such a long continuance of the limestone in contact with the particular magma now crystallized and visible where erosion has laid bare the zones of passage; and, moreover, that this fact explains the peculiarly favorable case for the proof of assimilation. The present reviewer is of opinion that the lack of

evidence for clearly defined endomorphic action leading to serious modification of eruptive magmas is, in many cases, due to a removal of the mixed zone of assimilation from contacts by bodily movement of the magma. Such a period of active assimilation and removal is followed by another of limited or no power of assimilation, during incipient cooling, and that stage by a third marked by the crystallization of essentially pure magma in contact with country rock, perhaps metamorphosed but not incorporated.

3. A striking argument for the modification of the granitite in this manner is afforded by certain inclusions within it, described as surrounded by the hornblendic basic types identical with those characterizing the main contacts.

4. No independent dikes, apophyses, or stocks of the basic rocks occur in the region, and on the right bank of the Oriège, at least, there is no dynamic action sufficiently intense to explain the presence of diorites, etc., in the granitite by any system of cross-faults.

5. Lastly, the absence of chilling phenomena in the stock, the intensity of the exomorphic metamorphism, the enormous number of apophyses in the slates, as well as other facts, all tend to show a condition of high temperatures for a long period, and of abundant mineralizers which are permissive of the large amount of recrystallization necessary to explain the occurrence of the basic rocks.

The mode of intrusion is implied in what precedes—a *mise en place* by progressive assimilation of the overlying terranes. The proofs of absorption of the quartzites and slates are not so strikingly manifest as those in the case of the limestone, but they are regarded by M. Lacroix as equally valid. On the other hand, neither block-faulting, nor the batholithic, nor the laccolithic hypothesis seems to be admissible.

On the whole, the memoir is seen to have its chief importance in upholding first, the doctrine of feldspathization of the metamorphic aureole about an intruded granite by the addition, in the presence of mineralizers, of feldspathic material from the granite's own mass; secondly, the doctrine of assimilation; and, lastly, the theory of the *mise en place* of intrusive granites, as enunciated by M. Michel Lévy. It is safe to say that, from the point of view of field observations and of comparative mineralogical study, these tenets of the French school of petrographers have never had in a single locality such strong confirmation. We shall look forward with interest to the forthcoming memoir

on the chemical relations of the rocks of this region. It may be that the analyses will explain certain difficulties which have suggested themselves, almost as a matter of course, in the way of explaining the formation of such minerals as hornblende and olivine (especially the latter) in the endomorphic zone of recrystallization. R. A. DALY.

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Bibliography and Index of North American Geology, Palæontology, Petrography, and Mineralogy for 1896. By F. B. WEEKS. (Bull. U. S. Geol. Surv., 149, 152 pp. Washington, 1897.)

Bibliografia Geológica y Minera de la República Mexicana. By R. AGUILAR y Santillán. (Bol. 10, Inst. Geol. de Mexico. 158 pp. Mexico, 1898.)

Students and workers in geology everywhere will be glad to receive the two papers here mentioned. The value of a well compiled and carefully edited bibliography is too well recognized to need any mention. To all active workers such books are indispensable. The two under review, fortunately, are both excellent. Mr. Week's good work in this line needs no introduction. It only remains to commend and to note the broadened scope of the bibliography. In its preparation 108 serials were examined, the number including several devoted to economic phases of geology and not previously listed. As usual the abstracts are concise, but are quite sufficient to determine the scope of the paper. The full indexes are especially valuable.

The bibliography of Mexico is especially helpful, because of the previous absence of any paper thoroughly covering the field. The author has had more than the usual difficulties, due to poor library facilities, the scattered and incidental nature of the papers, and the presence of broken sets of short lived serials. In the face of such materials there must necessarily be a certain amount of selection. Not all the papers listed are strictly geological but all will doubtless be helpful. At first glance the 1953 titles included seem formidable, and one is surprised at the amount which has been written, but a more careful examination shows, as remarked by the Director in his introduction, that the great majority of the papers written on the geology of Mexico are really technical engineering papers, and deal with geology

but incidentally. The present active geological survey of Mexico has a practically new field, and in view of this and the difficulties of communication over much of the republic, the rapidity of its publication and the high class of the work, deserve the heartiest recognition. Among the publications of the survey the present one will for sometime to come rank among the more useful. H. F. B.

Geological Survey of Kansas, Vol. III, 1898. By DR. E. HAWORTH, geologist, and MR. W. R. CRANE, assistant geologist and chemist.

Volume III is a special report on Kansas coals and treats of the coal mines and coal mining of the state in all their various aspects. The volume is divided in two parts.

Part I is by Dr. Haworth and deals with the general stratigraphy of the Kansas Coal Measures. Numerous detailed accounts of the strata are given to enable the reader to understand the general geological conditions of the Coal Measure area of the state. The geology of the area is further shown by the records of many deep wells with drawings illustrating the strata as shown by the wells, and in addition to these many geological sections crossing the state in different directions are given.

The following facts are gleaned from Dr. Haworth's report. The Mississippian or subcarboniferous outcrop occupies an area of about forty-five square miles in the extreme southeastern part of the state. The strata dip under the other formations of the state and their westward inclination is about 17 feet per mile, on the average. The Coal Measures proper occupy the eastern third of the state and constitute a mass of alternating layers of limestones or sandstones and shales aggregating 3000 feet in thickness. The limestones are similar in general character but the lower ones are more nearly crystalline, of finer texture, and denser in appearance. The following divisions of the Coal Measures, named in order from lowest to highest, are recognized: (1) The Cherokee shales; (2) The Oswego limestone; (3) The Labette shales; (4) The Pawnee limestone; (5) The Pleasanton shales; (6) The Erie limestone; (7) The Thayer shales; (8) The Iola limestone; (9) The Lane shales; (10) The Garnett limestones; (11) The Leroy shales; (12) The Oread limestone; (13) The Lecompton shales and Elgin limestone.

Part II of the report is by Mr. W. R. Crane and deals with the detailed stratigraphy as exhibited at the mines, the geographic location of the coal fields, the chemical and physical properties of the coal, mining methods and mining machinery, statistics of coal companies and coal mining laws. It contains the best exposition of the phenomena of "horsebacks" in the coal that has yet been published. The subject is fully illustrated by clear-cut drawings. Mr. Crane thinks the "horsebacks" are the result of fissures produced by vibratory movements of the strata, the fissures thus produced being filled with clay, either by the removal of pressure or by "creeping," these vibratory movements, he thinks, in all probability accompanied the Ozark uplift. Rolls and "bells" and other stratigraphical phenomena are explained.

According to the author there are 15,000 square miles of productive coal fields in Kansas but only a small proportion of this area is being worked at the present time. The mines most extensively worked are located in the southeastern part of the state. Across the coal area the percentage of fixed carbon in the coal and the value of the coal (selling price) increases from northwest to southeast. Coal is mined by stripping, drifting, pitting and shafting. In the shafts mining is carried on by means of "the long wall system" or "the room and pillar system."

To the author's exposition of the chemical and physical properties of the coals the greatest importance is attached. He performed the work in a very elaborate manner, the tests being made in many different ways, all the results of which are finally placed in a general summary. The illustrations of machinery, etc., used in the article are from the pen of the author and attest his ability as a draughtsman.

W. N. L.

Twenty-second Annual Report Indiana Geological Survey. W. S. BATCHLEY, State Geologist, Indianapolis, 1898.

The Twenty-second Annual Report of the state geologist gives a detailed statement of the work of the department of geology and natural resources, for the year 1897. Among the subjects treated in the volume is a paper on the "Geological Scale of Indiana," by W. S. Batchley and Geo. H. Ashley. This paper shows the geological formations of Indiana in vertical section, and gives the time, character of the rocks, and subdivisions of each group.

A paper on "The Geology of Lake and Porter Counties," by W. S. Batchley, is devoted mainly to the physiography of the two counties. The author states that the discussion is limited to this phase of geology "since not a single outcrop of rock occurs in the two counties." A considerable portion of the paper is devoted to the discussion of glacial phenomena.

An economic paper by the same author discusses "The Clays and Clay Industries of Northwestern Indiana." The paper treats in some detail of the origin, varieties, properties, impurities of clays and their analyses. Statistics are also given concerning the clay industry.

"Report on the Niagara Limestone Quarries" is the subject of a paper by August Foerste. This report contains a discussion of the uses, properties, and distribution of the stone. From this paper we learn that the variety known as "Laurel limestone" is the most valuable variety; that it occurs in natural slabs, is easily quarried, requires little dressing, is of a handsome color, and is very hard and durable.

The palæontology of the state receives attention through E. M. Kindle, who has prepared a "Catalogue of the Fossils of Indiana." The report also indicates the geological horizon of the species, and is accompanied by a bibliography of Indiana palæontology.

A contribution to the ornithological literature of the state is found in a paper entitled "The Birds of Indiana," by A. W. Butler. The paper contains descriptions of 321 species which have been identified within the state. It also treats of the songs, habits, and times of arrival and departure, of the birds.

Other papers in the report discuss mines, natural gas, and petroleum.

W. N. L.

Sixth Annual Report Iowa Geological Survey, Vol. VIII. By SAMUEL CALVIN, State Geologist. Desmoines, 1897.

This volume embodies the results of field work covering an area of five counties. An important part of the work has consisted in a careful determination of the location and extent of mineral deposits, clays, building stones, and other economic resources, including a valuable discussion of the drift sheets and other surface formations preliminary to a complete description of the soils of the state.

Of great interest to the people of Iowa will be the tabulated statis-

tics, at the beginning of the volume, relative to the year's economic production. The report closes with a paper on the "Properties and Tests of Iowa Building Stones," by H. Foster Bain, which cannot fail to prove of inestimable local value.

Although the directing motive in the work of the survey has been toward economic and practical ends, this report contains, as have preceding volumes, many discussions of general scientific interest. The treatment of strictly geological features, especially in their physiographic aspects, for thoroughness of preparation and clearness of presentation will prove, beyond doubt, to be a source of great interest to the geologists of the country.

The volume is admirably printed, and besides containing many new maps and diagrams, is judiciously illustrated by an expressive collection of photographs in half tone. J. W. F.

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BOWLDER-PAVEMENT AT WILSON, N. Y.

Bowlders in till when groupt in an approximately horizontal plane and striated on their upper surfaces in a common direction constitute a bowlder-pavement.[1] Considerable attention has been given to such pavements in Scotland, especially by the Hugh Millers, father and son. In 1859, O. N. Stoddard described a fine example near Miami University, O., but no other American observations have come to my attention.[2] While engaged, last summer, in field work of the United States Geological Survey, I came upon another example, which seems worthy of record.

The village of Wilson is situated about twelve miles east of the Niagara River and half a mile from the shore of Lake Ontario. One of its main streets runs to the shore, where a short pier juts into the lake. There are longer piers a little farther west at the mouth of Twelvemile Creek. On this part of the lake coast the movement of shore drift is from west to east, and this movement is locally obstructed by the piers. West of the piers there is an accumulation of shore drift, and the land gradually encroaches on the lake. East of them the defect of shore drift deprives the shore of its natural protection, and erosion is exceptionally rapid. At the Wilson pier the bluff due

[1] This is the usage of the Scottish geologists. The term has been employed in another sense by J. W. Spencer; see explanation of plate, p. 775.

[2] Diluvial Striæ on Fragments in Situ, by O. N. Stoddard. Amer. Jour. of Sci., 2d Ser., Vol. XXVIII, pp. 227–228.

Unpublisht observations by H. L. Fairchild and M. R. Campbell indicate allied phenomena at Rochester, N. Y., and Cleveland, O.

to the attack of the waves is twelve to fifteen feet high and free from talus, and the section is fully exposed for a half mile to the east. The lower part of the bluff is composed of till, eight to ten feet being visible, and the base not seen. Above this is laminated clay, a deposit spread by the waters of the glacial lake Iroquois.

To casual observation the till appears to be a single continuous body, but more careful examination shows that there are two parts separated by a horizontal line between five and six feet above the surface of the water. Both tills are reddish-brown, but there is a slight difference in color, the upper inclining toward orange and the lower toward purple. At various points a bitter efflorescence was seen on the surface of the upper till, and this was not observed on the lower. Both tills are moderately supplied with pebbles and bowlders, the material of the larger fragments being chiefly sandstone and limestone of the subjacent Medina and contiguous Hudson River formations, and ranging in diameter up to about twenty inches. There are also crystalline erratics from a distance, and a few of these are several feet in diameter. Such larger bowlders were not seen in situ in the bluff, but occur here and there on the beach and in shallow water near the shore, where they have evidently been left by the erosion of the enclosing till.

Just at the top of the lower till bowlders are comparatively abundant, and such as are flat lie with their greater dimensions horizontal. Their upper surfaces form parts of a level line drawn across the bluff (Plate XIV), and it was their alignment which drew attention to the compound character of the till. So far as the upper till betrays structure, its lamination is approximately horizontal. Much of the lower till is somewhat definitely laminated, and the lamination is contorted. In some places there are irregular masses of gray till mingled with the red, the general arrangement being suggestive of structures commonly seen in the Archean complex.

Examination showed nearly all the bowlders at the plane of separation to be striated on their upper surfaces. The directions

1

3

2

4

BOWLDER-PAVEMENT

of striation were observed in the cases of ten bowlders in situ, and found to be substantially parallel. Nine ranged between S. 45° W. and S. 50° W., and the tenth was S. 55° W. The accompanying illustrations (Pl. XIV, Figs. 1, 2, and 3) show the upper faces of two of the bowlders and the side of one. It seems clear that after the deposition of the lower till it was over-ridden by a glacier moving toward the southwest. This is the general direction of striation on the bed rock of the region, but no observation was made in the immediate vicinity of Wilson.

All the bowlders strongly glaciated on their upper surfaces were found to have one diameter less than the others, and to lie in such position that the least diameter was vertical. So far as observed, bowlders without pronounced differences in their several diameters were not more strongly glaciated on the upper side than on other sides, although lying at the same level as the others.

To account for these peculiarities, as well as for the accumulation of bowlders at the summit of the lower till, the following explanation is offered: The glacier which deposited the upper till slowly eroded the lower till as it moved over it. When this erosion began to uncover a bowlder, differential pressures resulted. In Fig. 1 the horizontal line represents the upper sur-

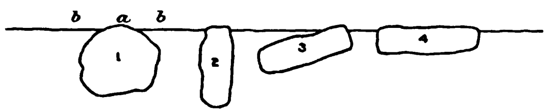

FIG. 1. Diagram illustrating theory of bowlder arrangement.

face of the till undergoing erosion, and 1 the discovered bowlder, projecting above the till at *a*. If the glacier were stationary it would mold itself plastically about this protuberance and press equally on *a* and *bb*, but as it is in motion and has great viscosity, the pressure is greater at *a* than at *bb*, and the differential pressure is not merely momentary, but continuous. It has the effect of a simple pressure on the bowlder at *a*, forcing it down into its plastic matrix, and as the erosion of the till continues,

the bowlder is steadily pusht downward. The erosion is thus rendered selective, the bowlders remaining as the fine material is carried away. The bowlders accumulated at the surface of the lower till are a residuum from the portion of the till which has been removed.

Combined with the vertical pressure at *a* is a horizontal pressure (from forward motion of glacier) tending to rotate the bowlder in its matrix. In the case of a rounded bowlder there may be rotation as long as it continues to be forced downward, but a flat bowlder eventually reaches an attitude of stability. If the longer diameter lies originally vertical or oblique (2 or 3, Fig. 1), there is a partial rotation bringing it to a horizontal position (4, Fig. 1), and rotation then ceases because the differential vertical pressure is applied to both edges of the rock, and any incipient rotation is checkt by increase of pressure on the rising edge. The horizontal attitude is thus stable, and a bowlder having once acquired it retains it as long as the process continues, being thereby enabled to receive thorough glaciation on its upper face.

If this explanation is correct, a bowlder-pavement records an epoch of local till erosion by a glacier. The epoch may be a mere episode interrupting a period of till deposition by the same glacier, or it may be a part of a stage of readvance following a long interglacial period. The demonstration of two tills at the Wilson locality does not by itself constitute an important contribution to the subject of the complexity of glacial history, for the removal of the upper part of the lower till has destroyed whatever evidence may have existed as to the length of time interval separating the two. The significance of the phenomenon can hardly be understood until it shall have been brought into relation with cognate facts from a broad field.

The observation may perhaps serve a more important purpose by directing attention to the possibility of gathering much information as to the direction and history of ice motion from the internal structure of till sheets. The second Hugh Miller not only found a body of information in bowlder-pavements, but

discovered that in certain Scottish and English tills the elongated fragments, large and small, are oriented in the direction of ice motion, so that he was often able from direct examination of the till to determine the direction of the ice current by which it was deposited.[1]

A bowlder-pavement, doubtless continuous with the Wilson, was seen at the lake shore, three miles west of the village, the plane of separation being two or three feet above the water level.

G. K. GILBERT.

EXPLANATION OF PLATE.

FIGS. 1, 3. Glaciated faces of bowlders from bowlder-pavement. $\times \frac{1}{2}$.

FIG. 2. Side of the bowlder represented in Fig. 1, showing even truncation of glaciated face. $\times \frac{1}{2}$.

FIG. 4. Till and bluff at Wilson, showing line of bowlders at horizon of bowlder-pavement. Sketch by H. H. Nichols, based on a photograph.[2]

[1] On Bowlder Glaciation, by HUGH MILLER, Proc. Roy. Phys. Soc. of Edinburgh, Vol. VII, pp. 156–189, 1884. This paper summarizes earlier literature, and is itself probably the most important contribution to the subject.

[2] The strand is thickly set with bowlders releast from the till by wave erosion. For such accumulations J. W. Spencer, doubtless unaware that the term was pre-occupied, proposed the title "bowlder-pavement." In each case the term designates a residuum from erosion, the process being in one case glacial, in the other littoral. It chances the view, drawn to show one kind of bowlder-pavement, illustrates the other also.

GEOGRAPHIC RELATIONS OF THE TRIAS OF CALIFORNIA.[1]

Historical.—Triassic fossils were discovered in California by the State Geological Survey under J. D. Whitney; these were rightly recognized by Gabb[2] as being nearly related to the Upper Triassic Fauna of the Alps, and certain species were even looked upon as identical with European forms. This was the first discovery of marine Trias in the western hemisphere, and the third discovery outside of Europe, the first being that in northern Siberia by Keyserling,[3] the second that in the Himalayas of India, by Strachey,[4] and later described by Salter.[5] Nothing more was done with the Trias in America until the Survey of the Fortieth Parallel discovered it in the Star Peak range of Nevada, where Meek[6] thought he recognized some Californian species. Shortly after this Lower Trias was discovered in southeastern Idaho, by the Hayden Survey, and described by Dr. C. A. White;[7] no Californian species were found here, but this discovery proved the occurrence in the West of a Lower Triassic fauna like that of the Asiatic region.

The next publication on the Californian Trias was by E. von Mojsisovics in *Arktische Triasfaunen*,[8] in which some of Gabb's species are compared with ammonites from Siberia, and the relations of the American faunas to those of the Arctic-Pacific province are discussed.

[1] Published by permission of the Director of the United States Geological Survey.

[2] Palæont. Calif., I, pp. 19–35.

[3] Bull. phys.-math. de l'Acad. Sci. de St. Petersbourg, Tome V, No. 11.

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[5] J. W. SALTER (and H. F. BLANFORD), Palæontology of Niti in the Northern Himalayas, 1865.

[6] Geol. Exp. Fortieth Parallel, Vol. IV, Part I, 1877.

[7] U. S. Geol. and Geol. Surv. Terr., Vol. XII, An. Rep., Part I, 1883.

[8] Mém. Acad. Impér. Sci. St. Petersbourg, VII Ser., Tome XXXIII, No. 6, 1886.

Professor Alpheus Hyatt[1] next undertook a revision of Gabb's work, visiting the original locality and adding largely to the faunal list, and especially to our knowledge of the stratigraphic distribution of the species.

In 1892 the writer's attention was called by Dr. H. W. Fairbanks to a bed of ammonite-bearing limestone near Pitt River in Shasta county; on examination the fossils proved to be of Upper Triassic age. This locality was soon afterwards visited by the writer, who spent the field season of 1893 at work in that region. This work added over fifty species to the known fauna, chiefly of Karnic age, and nearly related to characteristic species from the Tyrolean Alps.[2] The writer has since spent a good part of the field seasons of 1895 and 1898 collecting in that region, and has added greatly to the fossil list, especially of the Ceratitidæ and the Tropitidæ, bringing out even more strongly the relations with the Alpine Trias. A part of these results has already been published.[3]

The latest paper on the Triassic stratigraphy of California is by Dr. E. von Mojsisovics,[4] who, on the basis of communications of Professor Hyatt and the writer, and a suite of fossils sent him by the writer, compares at considerable length the American to the European Upper Triassic faunas.

The accompanying table is based on that published by the writer in *Classification of Marine Trias*, but revised and brought up to date so as to include the stratigraphic work of the past two years, and to give a satisfactory basis for the correlation of marine Triassic sediments for all known regions. Of course it is only tentative, merely the opinions of several men engaged in this study; but the wide distribution of such zone faunas as

[1] Bull. Geol. Soc. Amer., Vol. III, "Jura and Trias at Taylorville, California," pp. 397–400.

[2] JOUR. GEOL., Vol. II, No. 6, 1894, "The Metamorphic Series of Shasta county, California, and JOUR. GEOL., Vol. III, No. 4, "Mesozoic Changes in the Faunal Geography of California."

[3] JOUR. GEOL., Vol. IV, No. 4, "Classification of Marine Trias."

[4] Denksch. K. Akad. Wiss. Wien. (Math. Nat. Kl.), Bd. LXIII, 1896, "Beiträge z. Kennt. d. Obertriadischen Cephalopoden Faunen des Himalayas.

CORRELATION OF MARINE TRIASSIC SEDIMENTS.

Series	Stage	Substage		Zone Fossil	Mediterranean Region	Oriental Region	Arctic-Pacific Region	American Region
BAJUVARIC	Rhaetic		22	*Avicula contorta*	Koessen Beds	*Halorella* beds of the Pamir	*Monotis* beds of Rotti; *Stenarcestes* beds of New Caledonia	*Pseudomonotis* beds ? of Peru; Swearinger slates, Californian; Hosselkus limest'ne; of Queen Charlotte Islands
	Noric	Sevatic	21	*Sirenites argonautæ*	Noric Limestone of Hallstadt; Balia-Maden in Asia Minor			
			20	*Pinacoceras metternichi*				
		Alaunic	19	*Cyrtopleurites bicrenatus*				
		Laciacic	18	*Cladiscites ruber*		Himalayan Noric limestone		
			17	*Sagenites giebeli*				
TIROLIC	Karnic	Tuvalic	16	*Tropites subbullatus*	Sandling beds	Himalayan Karnic limestone	*Daonella* beds of Rotti; *Juvavites* beds of Tonquin, China	with *Subbullatus* and *Trachyceras* faunas; Trias Charlotte
		Julic	15	*Trachyceras aonoides*	Raibl beds			
		Cordevolic	14	*Trachyceras aon*	St. Cassian beds			Halobia beds
	Ladinic	Longobardic	13	*Protrachyceras archelaus*	Wengen beds		Nipon beds of Japan	Pitt Shales of Shasta County, California; Star Peak beds of Nevada
		Fassanic	12	*Dinarites avisianus*	Marmolata beds			
			11	*Protrachyceras curionii*	Buchenstein beds			
DINARIC	Anisic	Bosnic	10	*Ceratites trinodosus*	Upper Muschelkalk	*Ptychites rugifer* beds of the Himalayas	*Daonella* beds; Spitzenbergen; Beds of Russkij and Olenek	
		Balatonic	9	*Ceratites binodosus*	Lower Muschelkalk	*Sibirites prahlada* beds of the Himalayas		
	Hydaspic		8	*Stephanites superbus*		Upper *Ceratite* limestone of the Salt Range	*Posidonomya* beds	
SCYTHIC	Jakutic		7	*Flemingites flemingianus*	Zone of *Tirolites cassianus*; Werfen beds of the Tyrolean Alps; *Tyrolites* beds of Djulfa in Armenia	*Ceratite* limestone of the Salt Range; *Subrobustus* beds of the Himalayas	Olenek beds of Siberia	*Meekoceras* beds of ? Idaho; Santa Ana limestone of California
			6	*Flemingites radiatus*				
			5	*Ceratites normalis*				
	Brahmanic	Gandaric	4	*Proptychites trilobatus*		*Ceratite* marls of the Salt Range	Beds of Ussuri and Russkij	*Ceratite* limestone of Inyo County, California
			3	*Proptychites lawrencianus*				
			2	*Gyronites frequens*		Lower *Ceratite* limestone of the Salt Range		
		Gangetic	1	*Otoceras woodwardi*		*Otoceras* beds of the Himalayas		

those of the *Meekoceras* beds of the Lower Trias, of the *Trachyceras* and *Tropites subbullatus* faunas of the Tirolic series, and of the *Pseudomonotis* beds in the Arctic-Pacific region, makes interregional correlation a much easier task.

The nomenclature of the table is that of Diener, Waagen and E. von Mojsisovics,[1] with the exception that *Ladinic* has been substituted for *Noric*, and *Noric* instead of *Juvavic*, the controversy between Bittner and v. Mojsisovics having been settled by a committee of the leading Austrian geologists[2] agreeing to make this change, and by this recommendation being in part accepted by v. Mojsisovics. It is immaterial to American stratigraphers which names are used, but since the Alpine Trias is the type of the marine formation of this age we must use the original formational names given by the Austrian geologists, and in the original sense. It is, therefore, a cause for congratulation that the committee report has been so widely accepted, and for regret that E. von Mojsisovics is still inclined to cling to his new term *Juvavic* for the Hallstadt beds which he formerly called *Noric*.

LOWER TRIAS.

The Santa Ana limestone.—The first Lower Trias recognized in California was found by Dr. H. W. Fairbanks in a hard black siliceous limestone on the west slope of the Santa Ana range, Orange county, California. The fossils were submitted to the writer, and proved to be: a trachyostrachan ammonite, not otherwise determinable, an undetermined brachiopod, and *Pseudomonotis* aff. *clarai*. The ammonite makes the Mesozoic age probable, and the pelecypod makes almost certain the Lower Triassic age, for *Pseudomonotis clarai* is diagnostic for the Werfen beds, upper part of the Alpine Lower Trias. It seems quite possible that this formation in California may be the connecting link between the Mediterranean and the Oriental regions, for the furthest known eastward extension of the Mediterranean Lower Trias,

[1] Sitzungsberichte k. Akad. Wiss. Wien. Bd. CIV. Abth. I. Dec. 1895. Entwurf einer Gliederung der Pelagischen Sedimente des Trias-Systems.

[2] Zur Ordnung der Trias-Nomenclatur. Wien 1898.

that of Djulfa in Armenia, is still of Alpine type, with *Tirolites*? and *Pseudomonotis* conf. *clarai*. The connection that existed in Permian time between India and eastern and southern Europe, through Asia Minor, seems to have been cut off in the Lower Trias. But these faunas are too meager for this to be much more than mere speculation.

	Permian	Lower Trias			Middle Trias	Upper Trias
		Brahmanic		Jakutic		
		Gangetic	Gandaric			
Lytoceratidæ, *Nannites*		Himalayas ×				Mediterranean and California ×
Pinacoceratidæ, *Clypites*?			Salt Range ×			
Meekoceratidæ, *Koninckites*		Himalayas ×	Salt Range ×	Salt Range, rare ×		
Meekoceratidæ, *Meekoceras*		Himalayas ×	Salt Range ×	Mediterranean, Idaho ×	Salt Range ×	
Meekoceratidæ, *Kingites*		Himalayas ×	Salt Range ×	Olenek and Salt Range ×		
Meekoceratidæ, *Gyronites*?			Salt Range ×	Salt Range, Olenek ×		
Ptychitidæ, *Xenaspis*	Salt Range ×	Himalayas ×	Ussuri ×		Himalayas × ?	
Celtitidæ, *Dinarites*				Mediterranean Salt Range Arctic ×	×	
Tropitidæ, new genus						

The Ceratite limestone of Inyo county.—In 1896 Dr. C. D. Walcott discovered some ammonite-bearing limestones in Inyo county on the east side of Owens' valley ten miles east-northeast of Lone Pine, two or three miles south of the Eclipse mill,

and about 3000 feet up above the mill, on the trail from Independence ever the Inyo range to Saline valley. The fossils submitted to the writer were badly crushed and distorted, owing to the partial metamorphism that the limestone has undergone, so that they were not in condition for description of genera and species, nor for identification with known species. But the septa permitted the identification of several genera of ammonites with considerable certainty; none of them were higher than the ceratite stage, and some retained simple goniatitic septa, a combination which, in itself, would point to Lower Triassic age, even if all the genera were new. The genera determined were all ammonites, no others being recognizable. The list is given on page 780, showing the range and occurrence of these genera.

In the above list it will be seen that most of the genera are confined to the Lower Trias, or Scythic series, of India, and that while most of them range through the Brahmanic and Jakutic stages, they nearly all reach their greatest development in the Brahmanic, and are rare outside of it. Thus it is probable that the Ceratite limestone[1] of Inyo county belongs to the Brahmanic. Another bit of evidence is the occurrence of some undetermined ammonites not included in the above list, resembling *Otoceras*, which in Armenia occurs in the highest Permian and in the Himalayas in the lowest Trias, only a few feet above the highest *Productus* beds, the top of the Palæozoic.

This fauna is wholly unlike anything in Europe, or indeed anywhere else outside of India, but it resembles that described from the Salt Range by Waagen,[2] and from the Himalayas of India, and Ussuri Bay by Diener.[3] Some years ago it was pointed out by Mojsisovics in *Arktische Triasfaunen* that the Lower Trias of Idaho was closely related to that of the Arctic-Pacific region, although no certain comparison could be made. In the Californian fauna we have the best means of comparison

[1] So-called, because of the prevailing ceratitic type of the ammonites.

[2] Pal. Indica. Salt Range Fossils. Fossils from the Ceratite Formation.

[3] Pal. Indica. Ser. XV. Himalayan Fossils. And *Mém. Com. Géol. St. Petersbourg*. Vol. XIV. No. 3. Triadische Cephalopodenfaunen der Ostsibirischen Küstenprovinz.

with the Indian ammonites, through the monographs of Waagen and Diener. We may, then, assume as certain a connection of the Californian waters with the Oriental region during Brahmanic or Jakutic time, forming the *Arktis* of Mojsisovics, and a separation from the Mediterranean Triassic sea or *Thetys* of Suess. How intimate this connection was we cannot know until material good enough for the identification of species is found.[1]

The danger of inferring separation of provinces on the basis of too few fossils is shown by the following diagram, illustrating the relations of the Lower Trias of the Salt Range with that of the Himalayas, according to Diener.[2]

Himalayas	Salt Range
Muschelkalk	Upper Ceratite limestone
Subrobustus beds	Ceratite sandstone
Almost unfossiliferous	Ceratite marls
	Lower Ceratite limestone
Otoceras beds	Unfossiliferous
Permian	

The Permian faunas are closely related in both, and that of the Subrobustus beds is, in part, identical with the fauna of the Ceratite sandstone, while between these two horizons each province has unfossiliferous beds corresponding to strata rich in ammonites in the other. It is not, therefore, a justifiable infer-

[1] The writer hopes during the season of 1899 either to visit this locality in person, or to send some of his students there.

[2] Mém. Géol. Surv. India. Ser. XV. Himalayan Fossils. Vol. II. Part I, p. 177.

ence that they were connected in Permian time, and separated after that until Jakutic time.

Tirolites and other members of the Tirolitinæ are conspicuously lacking in the Indian region, and this is true also of the Inyo beds. On the other hand *Dinarites* is entirely lacking in the Lower Trias of the Himalayas, and in the Salt Range below the Ceratite sandstone of the Jakutic, the species described as *D. minutus* Waagen, from the Ceratite marls, having turned out to be a *Ceratites.* And since the Dinaritinæ are known in the Lower Trias of the Mediterranean region, the Inyo fauna seems to have been intermediate between that and the Indian, although much more intimately connected, during the Brahmanic stage, with the Oriental region.

Gabb[1] cites *Goniatites lævidorsatus* Hauer from a locality thirteen miles north of Owens' Lake, from the foothills on the east side of the valley. E. von Mojsisovics[2] says that this ammonite is not Hauer's species, and not even in the same genus with it, *Celtites*, but belong to the group of *Ceratites obsoleti*, subgenus *Danubites*, chiefly characteristic of the Lower Trias. It seems, therefore, that the credit for the discovery of this formation in California must be given to the State Geological Survey under Whitney.

MIDDLE TRIAS

Of the faunal relations of Middle Trias little is to be said, because undoubted fossils of this age are not yet known in the state, nor, indeed, anywhere in America. The writer[3] has described a series of siliceous slates that probably belong in part to the Muschelkalk, but the evidence is merely stratigraphic, the known fossils being too poor to be of any use. The occurrence, at Silverthorn's Ferry on Pitt River, of a number of indeterminable ammonites, one of which resembles *Ptychites*, holds out the hope of future decisive discoveries. It seems likely, too,

[1] Pal. Calif., Vol. I, p. 21.

[2] Arktische Triasfaunen, p. 20.

[3] JOUR. GEOL.; Vol. II., 1894, No. 6. The Metamorphic Series of Shasta county, California.

that a part of the Star Peak beds of Nevada may eventually be shown to belong here, as Professor Hyatt has long claimed, but as yet the evidence is not convincing.

UPPER TRIAS.

The Upper Trias of the Genessee valley, Plumas county, was discovered and described by the Whitney Survey; its fauna is decidedly Alpine in character, although all the species thought by Gabb to be identical with European forms have since been shown not to agree with them. Since that time Professor Hyatt[1] has visited this locality, and has added greatly to the fossil list, some of the newly discovered ammonites being doubtfully referred to Alpine species.

The Upper Trias of Squaw creek, Shasta county, was discovered by Dr. H. W. Fairbanks, who called the writer's attention to the locality. The writer has since spent a good part of three field seasons in collecting fossils, and in studying the stratigraphy of that region; part of the results of this work has already appeared in the JOURNAL OF GEOLOGY.[2] In the papers referred to the most important species have been listed, although later field and museum study has changed the list considerably, adding many new ones, and dropping several. The fauna contains a large number of *Trachyceras* (subgenus *Protrachyceras*), *Clionites*, *Arpadites*, *Polycyclus*, *Sirenites*, *Tropites*, *Eutomoceras*, *Juvavites*, *Sagenites*, *Nannites*, *Miltites*, *Arcestes*, *Halobia*, etc., of decidedly European type. Dr. E. von Mojsisovics is of the opinion that several of these may be identical with species characteristic of the Tyrolean Alps. The greater part of the fauna belongs to the Karnic stage, zone of *Tropites subbullatus* Hauer, which characteristic ammonite of the Sandling beds is also present in great abundance in the Squaw creek limestone, showing all the varieties known in the Alps.

In the papers cited above the writer has called attention to the occurrence of species *Trachyceras* along with *Tropites subbul-*

[1] Bull. Geol. Soc. Amer., Vol. III, pp. 397–400.

[2] Vol. II, 1894, No. 6; Vol. III, 1895, No. 4; Vol. IV, No. 4, 1896.

latus Hauer, *T. torquillus* Mojs., *T. Telleri* Mojs., and many others characteristic of the Tuvalic substage. In the Hallstadt beds of the Tyrol no such association as this is known; the *Trachycerata* do not occur higher up than the Julic substage, zone of *Trachyceras aonoides*, nor does the Subbullatus fauna appear below the Tuvalic. It is, therefore, a question as to whether the Julic fauna survived longer here than elsewhere, or whether the *Tropites subbullatus* fauna reached here earlier, in middle Karnic time. There is not yet enough evidence to decide this, but it all points to the latter alternative. The *Tropites* fauna is an immigrant fauna wherever known, appearing suddenly without local ancestors in the Alps, the Himalayas, and in California, in the upper part of the Karnic stage; thus it may be that its occurrence in California marks an earlier appearance, for it was probably endemic in the American region. In addition to this, the *Trachycerata* associated with the Subbullatus fauna all belong to the subgenus *Protrachyceras*, which is supposed to be characteristic of a lower horizon than *Trachyceras* itself, which genus has recently been found in the Upper Karnic of the Himalayas. Further, the Subbullatus fauna did not all reach California at the same time, *Homerites semiglobosus* Hauer, not appearing here until all the *Trachyceras* fauna, and most of the *Tropites*, with which it is associated in the Alps, had become extinct.

We have in this occurrence an interesting study in homotaxis; the *Trachyceras* fauna is homotaxial all over the world, so is the Subbullatus fauna, and yet their occurrence together proves that neither fauna was synchronous in its appearance in various parts of the earth, and that even the order of appearance of the two faunas is not the same in all regions.

The most comprehensive review that has appeared on the faunal geography of the Upper Trias is the chapter by Dr. E. von Mojsisovics, "Die Meere der Trias-Periode,"[1] in which all that is known of the distribution and relations of faunas of this period is given, and several pages devoted to the western Ameri-

[1] Denkschriften d. K. Akad. Wiss. Wien, Bd. LXIII, 1896, "Beitr. z. Kenntniss d. Obertriadischen Cephalopoden Faunen des Himalayas."

can Trias, based on the published writings of Gabb, Meek, Hyatt, Whiteaves and the writer, and upon personal communications from Hyatt and the writer. Mojsisovics here takes the view that the occurrence together of the Subbullatus fauna and *Trachyceras* in India and California shows a survival of the latter group beyond its time elsewhere; this is more likely true of India, where the survival consists of single species of genuine *Trachyceras*, but in California the fauna is almost too large to be a survival.

The most interesting fact brought out by a comparison of the Upper Trias of California with that of India and the Alpine Mediterranean region is its near relationship with the latter, most genera and many species being common to the two regions. On the other hand, not many genera and no species are now known to be common to California and India; this is contrary to what we should expect, knowing that during the Lower Trias California was closely connected with India, as shown by community of genera and possibly of species, and also that during this same time neither India nor California was closely connected with the Mediterranean Triassic sea. Great changes in physical geography must have taken place about the end of Lower Triassic time, of which we have a partial record; during the Muschelkalk several species are common to the Indian, the Arctic-Pacific, and the Mediterranean regions, thus showing an opening of connection between regions that before were separated.

This relationship of the Californian to the European faunas persists until after the middle of the Jurassic formation, when the Boreal fauna comes in; towards the end of the Lower Cretaceous the connection with India is again established.

It is hard to see how anyone that has studied the changes of faunal geography undergone by the western American region since Paleozoic time could believe in the permanency of the oceanic basins as they now exist. These shifting faunal relations can only mean rising and sinking of continental margins, cutting off and facilitating intermigration, alternately aiding and obscuring interregional correlation.

JAMES PERRIN SMITH.

THE PETROGRAPHICAL PROVINCE OF ESSEX COUNTY, MASS. I.

THE area of igneous rocks in Eastern Massachusetts, especially in Essex county, has been, as the late Geo. H. Williams said, "more discussed than any other similar region of the continent." But, while it is the subject of a considerable literature, no petrological study of the region has been made. A few investigators, notably Wadsworth and J. H. Sears, have described the rocks, but there has been little or no attempt to coördinate the results and to compare this region with other analogous petrographical provinces, although its resemblance to that of Norway has been noted by Rosenbusch, Brögger and others. It is with the aim of supplying this deficiency that these pages are written.

I have visited the region of Essex county several times and collected a large number of specimens from the various localities, so that my collections are fairly representative of the different types, and my knowledge of their occurrences and relationships sufficient to justify me in undertaking the present investigation. This paper will deal with the subject in a purely petrological way, since the general geological, structural and stratigraphical features are far too complex to be unraveled in occasional visits such as mine were. A number of occurrences of dike and other rocks which merit a more detailed description than is here possible will be published separately, probably, in the *American Journal of Science*.

I would express my sense of deep obligation to Mr. J. H. Sears, of Salem, who has made this region an object of study for many years and whose acquaintance with it is unequaled. He has been most cordial and liberal in giving me specimens which it would have been difficult for me to obtain otherwise, and has encouraged me most generously in undertaking the present investigation.

While the general geology of the region lies outside the scope of the present paper, yet it will be not amiss to give a sketch of its chief features. The igneous rocks of Essex county extend along the coast from Lynn to the New Hampshire line, and inland for a distance of about five to fifteen miles, covering an area of about 342 square miles. To the south igneous rocks of similar character, and probably genetically related, are met with in the Boston Basin, but this paper does not include them. In Essex county they form a long ridge "extending in a northeasterly direction until cut off by the sea. To the northwest and to the southeast of this extended axis we have rocks of a less crystalline character verging upward into distinctly sedimentary deposits."[1] The igneous rocks have broken through and are later than pre-Cambrian and Lower Cambrian strata, blocks of which, often highly metamorphosed, are met with at many points within the igneous area.[2] The igneous rocks are chiefly granites, quartz-syenites, syenites, nepheline-syenites, essexites, diorites and gabbros, cut by numerous dikes, and with later flows of rhyolite. According to Sears[3] these are all pre-Carboniferous. A geological map of Essex county, prepared by Mr. Sears, and published by the Essex Institute in 1893, has lately (1897) been revised by him[4] and will be referred to frequently.

PETROGRAPHY.

In the description of the rocks the ideas as to classification generally prevailing in this country will be followed, the age distinction being ignored, and the rocks grouped according to structure and chemical and mineralogical composition. The separation of the dike rocks is largely for convenience and involves no assumptions as to the question of the "Ganggesteine." A number of chemical analyses will be given, and the descrip-

[1] N. S. SHALER. 9th Ann. Rep. U. S. G. Surv., p. 542, 1889.

[2] J. H. SEARS, Bull. Essex Inst., Vol. XXII, 1890.

[3] SEARS, Bull. Essex Inst. Vol. XXVII, p. 112, 1895.

[4] Bull. Essex Inst., Vol. XXVI, 1894, and *ibid*, Vol. XXVII, 1895.

tions will be followed by a general discussion of the results and a comparison of this region with others of similar character.

Granite. — The rocks which belong in this class and which are the granitites of Rosenbusch, have been described by Wadsworth,[1] Shaler[2] and Sears.[3] They are very abundant in the region, covering large areas at Rockport, Gloucester, Manchester, Beverly, Essex and elsewhere, having a general northeast-southwest trend.

The specimens in my possession from these localities are all hornblende-granites containing more or less biotite. The structure is in general typically granitic, a porphyritic development of the feldspar being rare. They are quite coarse-grained, the texture being fairly uniform in the various specimens. Fine-grained forms are less abundant and occur on the borders, as will be described later. In color they are usually light mottled gray (Rockport, west Gloucester, Manchester), but often yellowish (Bay View, Eastern Point), or pink (Wolf Hill, Marblehead Neck), these last two being due to incipient decomposition. The granite of Bass Rock is darker and greenish, forming apparently a transition to the augite-quartz-syenite.

The quartz is often dark and smoky. The feldspars are of the usual light shades, with good cleavage, being salmon-colored only in the specimens from Wolf Hill. Hornblende and biotite are scattered not very abundantly through the mass in black irregular spots. These are the principal minerals seen with the naked eye, but at the quarries of Rockport and elsewhere a large number of accessories have been found, including danalite, fayalite, epidote, zircon, magnetite, apatite, fluorite, and others.

In the area about Rockport pegmatitic veins are not uncommon, made up of coarsely crystalline feldspar and quartz, the latter being occasionally amethystine. The granite, especially of Cape Ann, is largely split by joint planes, and also shows a strong tendency toward rifting. This has been investigated

[1] WADSWORTH, Proc. Bost. Soc. Nat. Hist. Vol. XIX, p. 311, 1878

[2] SHALER, 9th Ann. Rep. U. S. G. Surv., p. 605, 1889.

[3] SEARS, Bull. Essex Inst., Vol. XXVI, 1894.

very fully by Shaler.[1] Judging from the evidence of strain revealed by the microscope the rifting (and possibly the jointing in part) is largely due to dynamic action subsequent to the consolidation of the mass.

In thin sections are seen the following minerals; orthoclase, albite, microcline, hornblende, glaucophane, biotite, pyroxene, magnetite, zircon, apatite, and allanite.

The quartz is highly xenomorphic, being usually interstitial. In some cases (Bass Rock, Rocky Neck at Gloucester) it also occurs in small rounded anhedra, scattered through feldspar areas. A brecciated structure at the borders of the larger quartzes is not rare, and is associated with an undulatory extinction. Mineral inclusions are few, and are only zircons. Gas and liquid inclusions, the latter carrying a movable bubble, are quite abundant though small, and occur in streaks.

The alkali-feldspars are varied and deserve more extended study than the scope of this paper allows. They are chiefly orthoclase and albite, which are almost always intergrown so as to form highly typical microperthites and cryptoperthites. In general they are closely similar to those described by Brögger[2] and Ussing[3] from Norway and Greenland syenitic rocks, and their figures would answer for forms seen here. Cryptoperthitic development is relatively scarce, the majority being perthitic on a fairly large scale. Microcline also is not rare, but less abundant than the preceding. This and the orthoclase are apparently rich in soda. The feldspars are apt to be rather cloudy and dusty with decomposition products, and they often show a brecciated border and undulatory extinction. Inclusions of apatite and zircon are rare. A very little albite-oligoclase is seen in a few sections, showing well-developed twinning lamellæ.

Hornblende, the chief ferromagnesian mineral, is usually xenophorphic, crystal planes being seldom seen. It is in gen-

[1] SHALER, 9th Ann. Rep. U. S. G. Surv., pp. 583–588, 602–605, 1889.

[2] W. C. BRÖGGER, Zeit. Kryst., Vol. XVI, pp. 521–560, 1890, Pls. XXII, XXIII

[3] USSING, Medd. om Grönland, Vol. XIV, pp. 5–101, 1898, Pls. I, II, III.

eral olive-green and highly pleochroic; $\mathfrak{c}$ = dark olive-green, $\mathfrak{b}$ = dark greenish-brown, $\mathfrak{a}$ = yellowish-green. The absorption is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The extinction angle $\mathfrak{c} \wedge c$ is high, about 29° having been observed in sections cut nearly parallel to (010). In certain specimens, notably those from Eastern Point (Gloucester) and Magnolia, a bluish hornblende occurs not only as separate crystals, but as patches in the green hornblende, and is also found forming a fringe on the ends of large crystals of this mineral. This occurrence is somewhat analogous to that described by Cross[1] in a dike in Colorado, where he regards the blue hornblende as secondary. His dike was much decomposed, while these granites are quite fresh; but it seems probable that here also part of the blue hornblende is secondary. As will be seen later, they are quite common in the region, and in many cases are undoubtedly primary. Inclusions in hornblende are not abundant, a few grains of magnetite, allanite, zircon, and apatite having been seen. The green hornblende often yields a secondary brown biotite on decomposition.

Biotite is a very common constituent, the greater part being primary. The granite near Manchester, represented by specimens from several quarries, is essentially a biotite-granite, hornblende being absent. In the majority of occurrences, however, the biotite accompanies hornblende, and is present in less amount. Two varieties are found. One is very pale green, with rather weak pleochroism, the colors being almost colorless and delicate apple-green. This is probably to be referred to the cryophyllite discovered by Cooke,[2] and investigated by Clarke and Riggs.[3] The other, which is more abundant, is darker greenish-gray, and shows stronger pleochroism; a deep, almost opaque, greenish-gray and a pale olive-green. Sections parallel to the base show in convergent light a marked opening of the optic axes. This biotite is referred to lepidomelane (annite), but Clarke's researches have shown that several varieties exist.

[1] CROSS, Am. J. Sci., Vol. XXIX, p. 359, 1890.

[2] J. P. COOKE, Am. J. Sci. (2), Vol. XLIII, p. 217, 1867.

[3] F. W. CLARKE, Am. J. Sci. (3), Vol. XXXII, p. 358, 1886.

Both biotites are notable for their poverty in MgO, which will be discussed later. They frequently show signs of alteration, accompanied by the development of magnetite grains, and their laminæ are often bent and distorted.

Secondary biotite occurs in most of the less fresh specimens, of a chestnut-brown color and highly pleochroic. It forms small flakes arranged perpendicular to or in fan-shaped aggregates along the edges of hornblende crystals, of which it is an alteration product. In the granite from the east side of Wolf Hill (Gloucester) are seen small clusters of small biotite flakes of an olive-green color and independent of hornblende, which are probably primary.

Pyroxene occurs in a few of the granites, most abundant in that of Marblehead Neck, though always in smaller amounts than the hornblende or biotite. It is a colorless diopside in stout, columnar, rounded crystals, and shows no noteworthy peculiarity. Occasionally, as at Trumbull's quarry, West Gloucester, it seems to be derived from hornblende, analogously to the often-observed "magmatic" alteration of hornblende in eruptive rocks. In some sections of granites which are not quite fresh the pyroxene is uralitized to some extent.

Magnetite is present in most of the granites, but very sporadically and in extremely small amount. Zircon and apatite are likewise present in most of the specimens, the former being the more common, while apatite is wholly absent in many.

Allanite occurs in granite from a quarry near the Lighthouse on Eastern Point and in that from Marblehead Neck. In the former it is included in hornblende, in the latter in biotite. The sections are rather long, with pointed ends, and the extinctions, either parallel or at angles up to 36°, show that the habit is tabular parallel to *a* (100). The color is deep brown, with strong pleochroism; $\mathfrak{a}$ = light yellowish-brown, $\mathfrak{b}$ = chestnut-brown, $\mathfrak{c}$ = very dark brown; $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. A zonal structure is common, the borders being lighter than the interior. Allanite was first observed in Essex county by D. M. Balch[1] in

[1] Am. J. Sci. (2), Vol. XXIII, p. 348, 1862.

1862 in the granite of Swampscott, was reported from several places in Maine and Massachusetts by Iddings and Cross,[1] while Sears[2] has added a number of localities to the list.

A small grain of pink fluorite was seen in the granite from Squam Light, and colorless grains in that from Pigeon Hill quarry, Cape Ann. I could identify no danalite, which Shaler speaks of as rare and resembling garnet in thin sections.

For chemical analysis a typical fresh specimen was chosen from the large pit of the Rockport Granite Co.'s quarry, a hornblende-biotite-granite; sp. gr. 2.618 at 18° C. There is given for comparison an analysis already published[3] of the riebeckite-granite of Quincy, described by T. G. White.[4]

	I	II		I	II
SiO_2	77.61	73.93	BaO	....	none
TiO_2	0.25	0.18	Na_2O	3.80	4.66
Al_2O_3	11.94	12.29	K_2O	4.98	4.63
Fe_2O_3	0.55	2.91	$H_2O(110°-)$	trace	....
FeO	0.87	1.55	$H_2O(110°-)$	0.23	0.41
MnO	trace	trace	P_2O_5	....	....
MgO	trace	0.04			
CaO	0.31	0.31	Sp. Gr.	100.54	100.91

I Hornblende-Granite. Rockport Cape Ann, Anal. H. S. Washington.
II Riebeckite-Granite. Quincy Blue Hills, Anal. H. S. Washington.

The analysis of the Rockport granite is a typical one, fairly rich in potash, but low in lime and iron oxides. It resembles that of the Quincy granite, but the latter is lower in silica and higher in iron oxides. Although the composition of the hornblende is unknown, yet as its amount is small, the mineral composition can be approximately calculated as below in Ia, the biotite being assumed to have the composition $(K_2H_4Fe_4)Al_2(SiO_4)_5$ as given by Clarke from an analysis by Riggs.[5] The composition of the Quincy granite calculated as already published is given in IIa.

[1] Iddings and Cross, Am. J. Sci. (3), Vol. XXX, p. 108, 1885.
[2] Sears, Bull. Essex Inst., Vol. XXVI, p. 189, 1894.
[3] H. S. Washington, Am. Jour. Sci. (4), Vol. VI, p. 181, 1898.
[4] T. G. White, Proc. Bost. Soc. Nat. Hist., Vol. XXVIII, p. 128, 1897.
[5] Clarke, Am. Jour. Sci. (3), Vol. XXXII, p. 360, 1886.

	Ia	IIa		Ia	IIa
Quartz,	35.5	30.2	Hornblende,	2.0	....
Orthoclase,	28.2	27.2	Riebeckite,	....	12.3
Albite,	32.0	27.7	Glaucophane,	....	2.0
Anorthite,	0.5	....	Accessories,	0.5	0.6
Biotite,	1.3	....			

Micrographic granite.—On reference to Sear's geological map of Essex county it will be seen that surrounding the granite areas and forming a zone between them and the areas of augite-syenite and diorite is a belt of micrographic granite. I have only a few specimens which represent this facies, the best being from Eastern Point, Gloucester, and from near Coy's Pond, Beverly, which were kindly given me by Mr. Sears. These closely resemble the granites, but are dark reddish-brown, finer grained and with less quartz visible. In thin sections they show much the same features as the granites proper. The minerals are the same, but quartz is less abundant. The difference is mainly in structure. In these rocks a micrographic intergrowth of feldspar and quartz is extremely common. The quartz here appears as small rounded spots extinguishing simultaneously in patches in the large feldspars. A similar micrographic structure is described by W. D. Matthew[1] in soda-granite from St. John, N. B. He states, however, that here this structure is best developed in the central parts of the mass and is lost at the edges.

In regard to the composition, while no analysis was made on account of the decomposed condition of the specimens, yet it seems probable, judging from the microscopical examination, that these micrographic granites are intermediate in composition between the granite proper and the augite-syenite, with a silica content of about 70.

Enclosures in granite.—In the granites of Essex county are found in abundance streaks (*Schlieren*) and rounded rock masses of darker color and of finer grain than the surrounding rock, which are also common in granite areas elsewhere. They show

[1] W. D. MATTHEW, Trans. N. Y. Acad. Sci., Vol. XIV, p. 205, 1895.

an evenly granular, granitic structure, varying in texture from moderately to very fine grained and compact. In color they vary correspondingly from light to very dark gray the most compact forms being the darkest. To the naked eye they show the same minerals as the granite, but the ferromagnesian constituents are more abundant. The contact with the surrounding granite is nearly always sharp and clear.

Under the microscope the same essential minerals are seen as in the granite and their habit is much the same, except that all is on a smaller scale. The alkali feldspars are quite similar, hornblende and biotite occur in all cases, the former being generally more abundant. It is usually green and only occasionally shows a bluish hue. In certain rather dark masses from the Pigeon Hill quarry, near Rockport, there is found a peculiar hornblende which occurs in bundles of long slender rods. In color it varies from colorless to pale bluish-gray, the latter shows brilliant polarization colors especially on the edges, and extinguishes obliquely, $\mathfrak{c} \wedge c$ being about 15°. The pleochroism is rather strong, $\perp c$ colorless or pale yellow, $\parallel c$ bluish or deeper yellow-gray, though occasionally it shows no pleochroism. It is apparently a variety of glaucophane. The biotite is also like that of the granites. It is sometimes secondary about hornblende, and in one specimen from Bay View it occurs about magnetite in brown flakes arranged radially. Colorless diopside is not abundant and often shows signs of alteration. Magnetite, while not abundant, is yet more common than in the granite. Zircon is common and in specimens from Pigeon Hill quarry forms well shaped but corroded crystals of considerable size, one being 1.5^{mm} long. Apatite is present as an accessory, but allanite was not observed.

SiO_2	67.35	MgO	0.03
TiO_2	0.60	CaO	0.55
Al_2O_3	15.05	Na_2O	4.42
Fe_2O_3	1.23	K_2O	6.08
FeO	4.76	H_2O (110°—)	0.16
MnO	0.05	H_2O (110°+)	0.17
			100.45

An analysis was made of a rather dark, fine-grained specimen from Pigeon Hill quarry, whose sp. gr. was 2.69 at 17° C. It is notably less siliceous than the granite, contains more iron and lime and higher alkalis, though the ratio of soda to potash remains about the same. From its analogy with the analysis of rocks described below it may be called a quartz-syenite. Owing to the uncertainty of the composition of the hornblende and biotite no exact calculation of the mineralogical composition is possible. A rough estimate gives albite 36, orthoclase 33, quartz 16, hornblende and biotite about 12, and magnetite, etc., 3 per cent.

Akerite (*augitic quartz-syenite*).—The rocks belonging in this class were first noticed by Wadsworth[1] in 1885 and were later described more in detail by Sears.[2] Rosenbusch[3] has expressed the opinion that these are related to the akerite type of syenites, a keen observation which my study of the rocks fully confirms. These rocks are found chiefly in the eastern part of Essex county, in Essex, Beverly, Manchester, Gloucester, and on Cape Ann. They lie between or around the granite areas, are connected with nepheline-syenites on the south, and have a general northeast-southwest trend. They appear to be almost as abundant as the granites.

Although Sears speaks of the megascopic characters as being extremely variable yet all the specimens collected by myself, as well as those given me by him, are fairly uniform. These show a granitic structure and are usually coarse-grained. The color even of the freshest specimens is greenish, which varies in shade from a dark greenish black to a light shade of greenish gray. They weather to a reddish color as Sears observed. The bulk of the rock is composed of feldspar which is of a deep greenish color, often fresh and with glistening cleavage surfaces, at other times dull and waxy. Quartz grains are present in varying amount, some specimens showing considerable while others

[1] WADSWORTH, Geol. Mag., 1885, p. 207.

[2] SEARS, Bull. Essex Inst., Vol. XXIV, 1892, and Vol. XXV, 1893.

[3] ROSENBUSCH, Mikr. Phys., Vol. II, p. 127, 1896.

contain very little, but it is never wholly absent. Black spots of augite are abundant and magnetite is seen here and there.

The microscope reveals the presence of the following minerals: quartz, alkali feldspar, diopside, hornblende, biotite, magnetite, apatite, and titanite. Quartz is not very abundant and is the last product of crystallization, occupying the interstices between the other minerals. It is undoubtedly primary, but the extinction is very often undulatory. The feldspars are mainly microperthitic intergrowths of orthoclase and albite, and resemble closely those of the granite. Microcline is rare. The feldspars are highly irregular as a rule, though some crystal outlines are seen against interstitial quartz. The boundaries between the adjacent crystals are generally zigzag or brecciated, indicating that the mass has been subjected to stresses. Some small albites show beautifully fine and clear twinning lamellæ. As they occur in such brecciated areas they may be supposed to be secondary. The feldspars very commonly show signs of alteration which is evidenced by a cloudy appearance, or when the crystal substance is clear by the cleavage lines and cracks being filled with a greenish decomposition product, the exact nature of which could not be determined.

The pyroxene occurs in scattered crystals of irregular outline. It is nearly colorless or a pale greenish-gray, without pleochronism but with high extinction angles. It is not infrequently uralitized on the edges, and carries inclusions of magnetite, apatite, and titanite. Primary hornblende of deep green or brownish colors is common in some specimens, notably in those from Poorhouse Hill, Beverly, and Cape Pond, Rockport. This is also intergrown with the pyroxene in parallel positions. Biotite is extremely rare or entirely wanting in these rocks, and when present is almost certainly secondary. Magnetite and apatite, occasionally in very long needles, are more common than in the granite. Zircon is present but is less abundant. Colorless titanite is quite common, usually in almost square sections with oblique extinctions. No nepheline was to be found in any of my sections, although Sears notes its presence. Its occur-

rence with quartz would be certainly very anomalous. Aegirite also, mentioned by Sears, was wanting in the material examined by me.

An analysis was made of a nearly fresh, typical specimen collected from a newly blasted mass on Prospect street, Gloucester. It is neither extremely light nor extremely dark in color, and seems to be an average sample of these rocks. Its sp. gr. was 2.612 at 17° C. For comparison there is given in II the analysis of an acid akerite from Norway.

	I	II		I	II
SiO_2	66.60	66.13	MgO	0.36	0.04
TiO_2	0.76	0.74	CaO	2.21	0.81
Al_2O_3	15.05	17.40	BaO	none	....
Fe_2O_3	1.07	2.19	Na_2O	4.03	5.28
FeO	4.42	....	K_2O	5.42	5.60
MnO	trace	0.13	H_2O	0.41	1.22
				100.33	99.54

I Akerite. Prospect street, Gloucester. H. S. WASHINGTON, anal.

II Akerite (porphyritic). Between Thinghoud and Fjelebua, Norway. MAUZELIUS, anal. BRÖGGER, Zeit. Kryst., Vol. XVI, p. 46, 1890.

It will be seen that this analysis, which closely resembles that of the enclosure in granite, except the higher lime, is essentially that of a basic granite or an acid syenite. In this case I adopt Brögger's scheme of classification,[1] and consider that the limit between the syenites and the granites lies at the silica content of the prevailing feldspars, which are here orthoclase with about 66 per cent. and albite with about 68. These rocks, therefore, I would class with the quartz-bearing augite-syenites, in accordance with Wadsworth, Sears and Rosenbusch.

That the rock belongs to an alkali magma is evident from its high alkali content ($K_2O + Na_2O = 9.45$), and its close parallelism with the *more acid* of Brögger's akerites is shown by comparison with the analysis in II. It must be noted, however, that this is an extreme type, and that the akerites as a group are more basic. Probably some of the darker and presumably

[1] BRÖGGER, Zeit. Kryst., Vol. XVI, p. 55, note, 1890.

more basic specimens, such as one from the railroad cut just north of the Manchester station, would correspond to them. The rather high lime is to be noted, but this is used up in the formation of pyroxene, leaving none for lime-soda feldspar, which, as the microscope shows, is not present.

Nordmarkite (*mica-hornblende-quartz-syenite*).— In Shaler's geological map of Cape Ann[1] there is indicated on both sides of Squam River an area of igneous rock, which is called diorite. Sears,[2] after a careful study of all the occurrences, came to the conclusion that they are not diorite but "phases of the augite-syenite rock," an opinion in which I concur. These rocks are far more limited in their distribution than the preceding, being found chiefly in Shaler's "diorite" area in West Gloucester and along the Squam River. I have specimens also from Hospital Point, Beverly, and from Salem Neck. They are light-gray fine-grained rocks, of granitic structure, looking like fine-grained diorite, composed of a white mass of feldspar, with subordinate quartz, thickly sprinkled with black specks of biotite and hornblende. The specimens from Hospital Point and Salem Neck are porphyritic through the presence of rectangular feldspar phenocrysts, from five to ten millimeters in length, and a few small quartzes.

They show under the microscope a granitic structure, though the quartz is less apt to be interstitial and usually forms small rounded spots in the feldspars, but is not pegmatitic as in the micrographic granite. The feldspars are alkali-feldspars, but do not show much tendency to microperthitic intergrowth. For the most part they are orthoclase or soda-orthoclase in simple crystals or Carlsbad twins. Albite is present in smaller amount, showing fine twinning lamellæ, with the extinctions proper to that mineral. In the specimens from Shaler's "diorite" area biotite is almost the only colored constituent. It forms small brown or greenish-brown, strongly pleochroic flakes, which are only rarely altered at the borders with development of magnetite grains. A

[1] SHALER, 9th Ann. Rep. U. S. G. Surv., Pl. LXXVII, 1889.

[2] SEARS, Bull. Essex Inst., Vol. XXV, 1893.

green hornblende is rare in these specimens and pyroxene seems to be entirely wanting. Magnetite, apatite and zircon are pres ent in small amount. Aegirite, spoken of by Sears as often present, was not seen by me.

The specimens from Hospital Point and Salem Neck resemble these as far as the quartz and feldspars go, though these are finer in grain and microcline is more abundant. The biotite is also identical. A fresh, primary, greenish-gray pleochroic hornblende is abundant. Both minerals are much corroded. Magnetite and apatite are more abundant, zircon in about the same amount. These rocks are apparently transition forms toward a more basic variety, represented by specimens from Concord street, West Gloucester and from several points south of Shaler's area. The latter are darker in color, due to greater abundance of biotite and hornblende. They are like those just described in thin section except that there is less quartz, and hornblende and biotite are more abundant, the former predominating. While no plagioclase or nepheline was seen, they seem to be connecting phases with the diorites and essexites of the region near them.

For the analysis representing these quartz-syenites a specimen was chosen from the west end of Wolf Hill, northwest of Gloucester, which, although not far from the granite, was fresh and seemed to be representative of the rocks of Shaler's area. For comparison is given an analysis of nordmarkite from Norway.

	I	II		I	II
SiO_2	68.36	64.02	CaO	1.85	1.00
TiO_2	trace	0.62	BaO	....	....
Al_2O_3	16.58	17.92	Na_2O	3.97	6.67
Fe_2O_3	0.90	0.96	K_2O	5.27	6.08
FeO	3.24	2.08	$H_2O(110^\circ-)$	0.18	....
MnO	trace	0.23	$H_2O(110^\circ+)$	0.17	1.18
MgO	0.45	0.59			
				100.97	101.37

I Nordmarkite, Wolf Hill, Gloucester. H. S. WASHINGTON anal.

II Nordmarkite, Tonsenaas, North of Christiania. JANNASCH anal. BRÖGGER, Zeit. Kryst., Vol. XVI, p. 54, 1890.

The close resemblance of this analysis to those of the granite enclosure and the akerite is evident, the main difference being in the silica, while, like the akerite, it is richer in CaO and MgO than the enclosure. It also closely resembles the analysis of nordmarkite from the Christiania region, although rather more acid and with less alkalies. Since it corresponds to these in mineral composition the name of nordmarkite is justified, especially as the akerites are a more basic group, while the nordmarkites are essentially more acid in their characters and affinities. It may be noted *en passant* that here also, as in so many cases elsewhere, we meet with biotite and hornblende occurring in the more acid, while pyroxene occurs in the more basic, members of the same series.

Nepheline-syenite. — The rocks belonging here, first noticed by Streeter, have been described by several petrographers, of whom may be mentioned Kimball,[1] Wadsworth,[2] Sears [3] and Rosenbusch.[4] They are not abundant in the region and are confined to an area along the coast about eight miles long and much less wide, extending from Salem Neck to Gale's Point, Manchester, and including the islands in and near Salem Harbor.

These rocks, as is usual, are prone to variation so that there is much variety among the specimens, even from the small area of Salem Neck. Structurally they may be divided into two groups, a granitic and a trachytic, which correspond to the ditroite and foyaite of Brögger.[5] One or two representatives of Brögger's laurdalite-structure were found, but not in typical development. While the two main structural types shade into one another the foyaitic seems to predominate, or at least there is a strong tendency to foyaitic development.

The ditroites from Salem Neck, Great Haste Island and Mackerel Cove are not very coarse-grained rocks, of dull gray

[1] KIMBALL, Am. Jour. Sci. (2), Vol. XXIX, p. 67, 1860.

[2] WADSWORTH, Geol. Mag., 1885, p. 209.

[3] SEARS, Bull. Essex Inst., Vol. XXIII, 1891.

[4] ROSENBUSCH, Mikr. Phys., Vol. II, p. 185, 1896.

[5] BRÖGGER, Zeit. Kryst., Vol. XVI, p. 39, 1890, and also ERUPTGEST, der Krist. geb., Vol. III, p. 165, 1898.

color and granitic structure. The feldspar is white; nepheline gray or brownish, with occasional yellow or gray cancrinite and blue sodalite which is abundant in certain veins on Salem Neck and elsewhere. Biotite, hornblende and aegirite are common, but are very irregularly distributed. Often they are scattered uniformly through the mass, but again they are rare or else abundant, and any one may predominate to the exclusion of the others. Occasional small brown crystals of zircon are seen, often of some size, but it never rises above the rank of an accessory, so that the name zircon-syenite, which has been applied to these rocks is quite unjustified. Magnetite is not uncommon, sometimes in large grains, and pyrrhotite is seen in one specimen.

In thin section the feldspars, chiefly albite and orthoclase, show less tendency to microperthitic intergrowth than in the granites, though such are not rare. The orthoclase is frequently in Carlsbad twins, and the albite shows twinning lamellæ, but both are found in simple crystals. Microcline, spoken of by Rosenbusch as abundant, is rare in my sections. The nepheline calls for no special comment. While usually interstitial between the feldspars, small, stout prisms are often included in them. Sodalite is rare in the sections. In the rock from Mackerel Cove and from Great Haste Island it occurs decomposed to a dull, fine-grained aggregate (*Spreustein*) interstitial between the feldspars. This decomposition has taken place while the nepheline has remained perfectly fresh. Cancrinite, colorless in thin sections, was observed in the syenite from Salem Neck in small amount, but elsewhere was rare. It was identified by its cleavage and high birefringence.

Perhaps the most common of the ferromagnesian minerals is a deep brown, highly pleochroic biotite, which forms thick plates or stout prisms. An olive-green biotite also occurs on Salem Neck, but is much less common. Hornblende is not very abundant, except in the foyaites of Salem Neck. It is greenish-brown, or a deep olive-green, and highly pleochroic, and much resembles the aegirite. In a few cases it occurs as a border around

aegirite. The pyroxenes are represented by a very pale, greenish-gray aegirite-augite ($\mathfrak{c} \wedge c = 34°$) and by green aegirite. The former occurs in quantity only in one specimen from Salem Neck with biotite. The ægirite is abundant in many sections, often in those free from biotite. It is clear grass-green, with strong pleochroism: $\mathfrak{a}$ = deep grass-green, $\mathfrak{b}$ = grass-green, $\mathfrak{c}$ = light greenish-yellow. The extinction $\mathfrak{c} \wedge c$ is about 7°.

Titanite, magnetite, and zircon are rare; apatite occurs in patches, but is not common. No eudialyte was seen. A few grains of a yellow, strongly pleochroic mineral, referred to laavenite, were found.

	I	II	III
SiO_2	58.77	59.31	60.39
TiO_2	0.31	0.32	....
ZrO_2	0.11	....	....
Al_2O_3	22.64	22.50	22.51
Fe_2O_3	1.54	1.93	0.42
FeO	1.04	1.40	2.26
MnO	trace	trace	0.08
MgO	0.19	0.17	0.13
CaO	0.74	0.46	0.32
BaO	none	....	....
Na_2O	9.62	7.98	8.44
K_2O	4.89	4.08	4.77
$H_2O(110°-)$	0.07	0.15	....
$H_2O(110°+)$	0.90	1.12	0.57
	100.82	99.42	99.95

I Nepheline-Syenite. Salem Neck. H. S. Washington anal.

II Nepheline-Syenite. Great Haste Island. H. S. Washington anal.

III Litchfieldite. Litchfield, Maine. L. G. Eakins anal. BAYLEY, Bull. Geol. Soc. Amer., Vol. III, p. 241, 1892, contains trace of CO_2.

The foyaites show their structure in the hand specimen very clearly, most surfaces exhibiting a multitude of long, glistening cleavage surfaces of feldspar, arranged in parallel position, forming a sort of flow structure. Surfaces in one direction, however, are made up of flat isometric feldspar plates, owing to the tabular development of the crystals parallel to *b* (010). They are clear ash-gray, and not very fine grained. In thin section they

differ from the preceding chiefly in the structure, which is eminently trachytic. The minerals are much the same, and the feldspars differ only in habit.

Two analyses of the nepheline-syenites were made, one of a specimen from Salem Neck west of the Fort, which was collected on the excursion of the A. A. A. S. in August 1898, under the guidance of Mr. Sears; the other of a specimen from Great Haste Island, given me by that gentleman. The former is foyaitic in microstructure, the latter more ditroitic. Both are apparently quite fresh. Analysis III, of litchfieldite, is introduced for comparison.

The two analyses resemble each other very closely, except that the former has more soda and less iron oxides. Compared with nepheline-syenites from other regions, the Salem rocks are notably poorer in lime and magnesia, and rather higher in silica than most. In these respects they correspond closely to the nepheline-syenites of Litchfield, Maine, and Red Hill, New Hampshire, described by Bayley,[1] especially the former. This is an extremely albite-rich type, to which he has given the name of Litchfieldite. Bayley regards the orthoclase as secondary for the most part, but it is to be observed that, even if it owes its present form to secondary processes, it must have existed in the original rock. Although the composition of the ferromagnesian minerals in the Salem rock is not known with certainty, yet a rough estimate may be made of its mineralogical composition. This is given in **Ia,** the composition of the Litchfield rock as calculated by Bayley from good data being given in **IIIa.** It will be seen that there is much similarity between the two.

	Ia	IIIa		Ia	IIIa
Albite	43	46.9	Lepidomelane	..	6.9
Orthoclase	27	27.0	Biotite, etc.	6	...
Nephelite	20	17.0	Zircon, Magnetite, etc.	3	...
Cancrinite	1	2.0			

Pulaskitic Syenite.—In connection with the nepheline-syenites, and constituting a facies of them, are found rocks which

[1] BAYLEY, Bull. Geol. Soc. Amer., Vol. III, p. 231, 1892.

are either extremely poor in, or quite wanting in, nepheline. These are true syenitic rocks and among my specimens two main varieties may be distinguished. They shade into the preceding group by imperceptible gradations.

The first is found at a quarry on the north shore of Salem Neck, west of the Fort, and is essentially a border facies near the contact with essexite, which crops out close by on the other side of a small hollow. This is typically foyaitic (trachytic) in structure and shows the tabular feldspars and their parallel arrangement. A variety of this, met with farther east near the water's edge, is brownish and porphyritic through the presence of abundant feldspar tables strewn irregularly in a feldspathic groundmass. These syenites resemble the foyaites in all essentials, except that nepheline is absent and the feldspars are nearly always microperthitic. The colored minerals are olive-green hornblende, brown biotite, and green aegirite, all in about the same amount. Magnetite grains and an occasional apatite needle are also found.

This rock corresponds closely, both in evident structure and mineral composition, to the hedrumite of Brögger[1] from the laurdalite region, and which he defines as: "nepheline-poor to nepheline-free syenitic rocks with trachytic structure exactly corresponding to that of the foyaites." Since, however, its analysis (I) shows that it is decidedly more acid than Brögger's analysis of hedrumite, it would better be classed with the pulaskites.

The other type of syenite forms coarse-grained masses and veins in the nepheline-syenite, and is best represented by a specimen from Salem Neck given me by Mr. Sears. This shows a coarse-grained mass of pearly, tabular, alkali-feldspar crystals, arranged in radiating groups, with a little aegirite, etc., in black grains and a minute amount of magnetite. Under the microscope the feldspar tables are seen to be microperthite, though kryptoperthite is also seen, as well as albite alone, showing fine and clear twinning lamellæ. There is possibly a slight admix-

[1] BRÖGGER, Zeit. Kryst, Vol. XVI, p. 40, 1890. It is more fully described later in Erupt. gest. d. Krist. geb., Vol. III, pp. 183 ff., 1897.

ture of the anorthite molecule. The only colored component seen in the sections is a grass-green aegirite, but other ferromagnesian minerals are probably present. The large crystals are well shaped, but have borders of detached aegirite grains which are embedded in the surrounding feldspar. These grains extinguish simultaneously with each other and with the large crystal, forming a sort of pegmatitic zone. The aegirite has been apparently cariously corroded by the magma and the hollows filled with feldspar substance. Nepheline occurs very sparingly in small interstitial spots.

An analysis of this type yielded the results below, in II:

	I	II	III	IV
SiO_2	63.71	63.09	64.54	63.71
TiO_2	trace	0.45	trace	0.86
ZrO_2	....	0.06	....	....
Al_2O_3	18.30	18.50	18.13	16.59
Fe_2O_3	2.08	2.90	2.63	2.92
FeO	2.52	1.36	0.97	0.66
MnO	trace	trace	....	0.20
MgO	0.09	0.16	0.67	0.90
CaO	1.18	1.00	0.62	3.11
BaO	....	....	0.42	....
Na_2O	6.39	7.25	6.60	8.26
K_2O	6.21	5.23	5.99	2.79
$H_2O(110°-)$	0.09	0.21	....	....
$H_2O(110°+)$	0.17	0.62	0.31	0.19
P_2O_5	....	....	trace	....
	100.74	100.83	100.88	100.19

I Pulaskite (hedrumitic). Salem Neck. H. S. WASHINGTON anal.

II Pulaskite. Salem Neck. H. S. WASHINGTON anal.

III Pulaskite. Fanisvand. BRÖGGER. Erupt. gest. Krist. geb. III, 198. 1898.

IV Umptekite. Bank of the Umpjaur. Kola Penin. Finland. ROSENBUSCH. Elemente d. Gesteinslehre. 1898, p. 112. No. 5.

It is decidedly more acid than the normal type, carrying less alumina, a little more lime, and about the same amount of alkalis. It is evidently a rather acid syenite, but its real affinities are uncertain. It bears a resemblance to the umptekite which Ramsay observed on the borders of the nepheline-syenite of Kola, and it is of interest to note that Rosenbusch speaks of

umptekites occurring at Curtis' Point, Beverly, and other localities of the Massachusetts region, and also refers the nepheline-syenite of Red Hill, N. H., to this type.[1] The umptekites, however, are typically soda-hornblende rocks, and markedly higher in lime and magnesia, as seen in analysis IV. They certainly show greater analogies with the pulaskites as defined by Brögger: "Nepheline-poor to nepheline-free rocks, also quartz-free or very poor in quartz, poor in dark minerals and with eugranitic structure, in which a development of the feldspars with rectangular or long rectangular sections predominates." It is of interest to observe also the affinity with the albite-rich litchfieldite. A rough calculation of the analysis II gives albite about 58.5 per cent., orthoclose about 31.5, anorthite about 2, and the rest (8 per cent.) colored minerals and magnetite. This rock, then, may be called a pulaskite, or rather a pulaskitic phase of the nepheline-syenite. It must be borne in mind, however, that both this and the hedrumite are only facies of the main foyaitic mass, and not independent rock bodies, at least so far as is yet known.

Orbicular syenite.—A small but interesting type of syenites is found near Bass Rock, Gloucester, and also, according to Mr. Sears, at Salem Neck, Beverly, and on the Manchester Shore, the development being in all cases quite local. Near Bass Rock, the only locality examined by me, it occurs as rounded inclosures in an outcrop of granite, apparently in place, together with similar masses of a dark, coarse-grained dioritic rock, which will be described later. A narrow compound dike of aplite cuts the granite and its inclosures. Of the occurrence of Mr. Sears' specimens I have no data at hand. The syenites are fine-grained and compact, with a groundmass of a light-gray color. Scattered through this are phenocrysts of black hornblende some 0.5 c.m. long, each hornblende being surrounded by a narrow zone of white, finely granular feldspar. These small areas of black with white borders give a peculiar orbicular appearance to the specimen.

[1] Cf. ROSENBUSCH, Elemente d. Gesteinslehre. 1898, pp. 113.

Under the microscope the groundmass is seen to be finely granitic in structure, and to be composed largely of alkali feldspar in xenomorphic grains, microperthite being rare, with only an occasional plagioclase grain. There are also present, somewhat abundantly, small, clear, rectangular sections of orthoclase. A little quartz occurs, especially as small interstitial grains. Irregular anhedra of colorless or very pale greenish-gray diopside are scattered through the groundmass. These are often surrounded by a zone of green or bluish-green pleochroic hornblende, which does not seem to be secondary. Magnetite grains, often surrounded by an amphibole halo, are not uncommon, and small apatite needles are met with.

The large black spots consist essentially of an olive-green, slightly pleochroic, hornblende. These hornblende areas are not continuous, but are made up of more or less rounded spots of hornblende, between which lies a granitic mesostasis of feldspar grains like the groundmass. The small hornblende spots in each area have their cleavage cracks parallel and extinguish simultaneously, so that the structure is micropoikilitic. The white borders are of granular feldspar, free from pyroxene, in which the small rectangular orthoclase sections seem to be more common. They pass insensibly into the surrounding groundmass.

A specimen given me by Mr. Sears from Salem Neck (?) is similar, but the structure of the groundmass is more trachytic, the pyroxene is largely replaced by dark green biotite, and the hornblende phenocrysts are much darker in color. The orbicular spots are quite ophitic in structure, owing to the tabular development of the feldspars. No analysis of these rocks has yet been made.

HENRY S. WASHINGTON.

(To be Continued)

THE GENETIC CLASSIFICATION OF GEOLOGICAL PHENOMENA.

In the consideration of every branch of natural knowledge, one of the first phases to receive attention is some ready means of comparing the various phenomena presented. Gradually there grows up some systemization of the facts and principles, that afterwards reflects the particular stage that the branch at that time attained. This orderly arrangement is the initial step in raising the branch to the dignity of a science.

Scientific advancement may be measured by the degree of taxonomic completeness shown, and by the character of the criteria regarded as critical. As progress is made a rapid evolution in the fundamental plan of grouping the facts takes place. In the beginning, a classification, crude though it may be, is outlined from those superficial features that, at first glance, are the most striking. This is, at a later stage, modified to one in which similarity of common characters, irrespective of natural relations, is taken into account. A vastly more advanced conception is classification based upon affinity, in which for similarity of features is substituted similarity of plan. The final stage is one in which origin, or causal relationship, is the governing principle. This is genetic classification.

At the present time the science of geology is just entering upon the stage last mentioned. As yet, no complete genetic scheme has been proposed. However, various attempts have been made to emphasize the principle of genetic association. All of these efforts appear to be too closely wrapped up in the older conceptions to show very much real advancement over them. They plainly indicate that the time is now ripe to seriously plan for a purely genetic arrangement of geological phenomena.

The older text-books on geology treat of all things geological

from the standpoint of the finished products. The idea that the latter are the visible expressions of many and constantly changing agencies has received only indirect or secondary practical consideration. As a result the production of many, if not most, geological features are loosely, or in a very vague way, ascribed to causes that are very complex. That is, instead of being single and simple the ascribed agencies are in reality a combination of several very distinct causes. For example, rock weathering is usually spoken of as if it were a single process in operation; whereas it involves the action of at least three distinct forces, one of which is strictly physical and the other two chemical, that are called into play separately or in conjunction.

So far as concerns the standpoint of treatment, the newer text-books on geological science are not much of an improvement over the older ones. The antiquated plans of making the products all important and of not distinguishing between processes still thoroughly permeate them. In some cases a little more space than formerly is devoted to "dynamical" geology, and a little less stress is placed upon the so-called historical section. Otherwise, there is relatively small difference between the geological manuals of today, and those of a quarter or a half century ago.

At this time it is not quite clear just what are the real reasons for this lagging of the manuals so far behind the science itself. Not the least important factor probably is that, as a rule, the makers of popular text-books are not in a broad way creative or productive investigators. The advance movement in geology began nearly a score of years ago, and today it is quite generally appreciated by all active workers, who face the subject in nature.

While it was only natural that geology should finally come to be placed upon a strictly genetic, or philosophic, basis, it was due primarily to the modern geographic school that the first strong impulses in this direction were given. The geographers, however, have not developed their side of the subject in as purely a genetic manner as they would have us believe, or as their opportunities permit. They certainly began in the right way, but in

the multitude of new conceptions and the maze of geographic forms that were presented, the analysis of the simple processes that were continually at work was largely overlooked.

So far as I am able to see, Gilbert appears to be the only one who has yet struck the right chord in the attempt to classify, by the processes, geological phenomena. As long ago as 1884 this writer proposed a "Plan for a Subject Bibliography of North American Geology," in which the geological agencies, instead of products are given primary consideration. How far the scheme would have been developed had it been allowed to go on cannot now be inferred. Since that time nothing further has been done in regard to this matter. The arrangement, presenting partly the common subdivisions of the subject of geology as given in our text-books, indicates that the author did not have in mind a classification that can be regarded as strictly genetic.

A few years later McGee suggested "a purely genetic taxonomy of geology, designed to include geography." This plan is particularly instructive as illustrating another phase of the subject. A critical examination of the scheme clearly shows that it is not really genetic except in name. Each product is made to have a constructive and a destructive phase. This plan has been, it may be here mentioned, seized with avidity by the more progresssive geographers. Its method is particularly attractive when applied to topographic forms, especially since it has been fully recognized that they all have "life histories." It is manifest, however, from the whole treatment of the theme that this plan has for its actual foundation the product and not the process. Stages of construction and of destruction must necessarily center around the feature and not the agency producing it. The essential characteristic of this scheme is the twofold nature of the production of every geographic form. When it is remembered that in the old geology the product is the all important factor, and in the new the process, it is at once seen that the dual plan is based entirely upon the old conception, and that the truly genetic principle is lost.

The plans of classification by genesis that have been formu-

lated by the geographers have to be made much more comprehensive than they now are, before they can accomplish their intended service. To begin with, an adequate scheme should be based directly upon geological agencies. Topographic features are largely only the outward expressions of the internal arrangement of the earth. The two groups of characters should be paralleled. One represents form — the physiognomy; the other structure — or anatomy. Yet some geographic features have no measurable equivalent in structure; and many structures do not give rise directly to distinctive forms of surface relief.

In a strictly genetic arrangement, where the processes and not the products are made the central theme, the continual operation of two antagonistic forces does not really exist. Constructive and destructive agencies can be recognized only when the phenomena are made the basis of the scheme. Processes are merely operative. If coupled with the products at all, in classification, all must be regarded as formative or constructive. The product's destruction, its loss of identity, is wholly immaterial. The action of agencies is merely to produce constant change.

A truly genetic scheme for the classification of natural phenomena thus always has prominently presented its underlying principle of cause and effect. All products must find accurate expression in terms of the agencies. Only then are the broader distinctions in geological classification rendered possible. The various taxonomic groups are made separable only when it is recognizable how, or in what manner, the component parts of the materials dealt with are influenced. Under one set of agencies and conditions a rock-mass is affected in one way, and the component units act altogether differently from what they do under another set of agencies. The primary groupings of the geological processes must be based, therefore, upon the manner in which these agencies affect the rock materials.

When rocks, or the materials with which geology has to deal, and through the medium of which geological phenomena take definite form, are carefully considered with reference to

their behavior under different physical conditions, it is found that, broadly speaking, they are acted upon in four very distinct ways: (1) In a most comprehensive manner all the rocks of the globe act as a unit, and are affected as such by only the cosmical forces. They are then considered in their astral relations. (2) Again, physical forces may affect rocks as great bodies, masses or formations. This may be regarded as their corporeal aspect. (3) Rocks may also be influenced only as particles. They are then treated of in their molar relations. (4) Finally, rocks are changed by the motions of their molecules and atoms. The molecular agencies, as understood in this connection, are those commonly termed physical (in its most limited sense) and chemical. Since, for geological purposes, it is hardly necessary to make any distinction between the two processes of this class, both are called molecular.

Each of the main groups, or kinds of geological processes, has its several minor categories, and each of these its particular phases. Activity of the subordinate agencies as comprehended under the latter give rise to the various classes of geological structure and geographic form.

While a complete arrangement of all geological phenomena, according to the plan suggested, would necessarily require a critical inquiry into the whole subject of geology, some of the principal features of such a genetic scheme may be indicated by the accompanying outline.

From this arrangement may be readily inferred many of the shortcomings of our existing systems. Two points are also prominently brought out. One is the frequent origin of very similar products through the action of diverse processes. The other is the complicated nature of most of the agencies that we commonly regard as simple. The absolute necessity is thus shown for a new series of brief, self-explanatory terms that will enable us to express with exactness the various processes according to the modern view or modified conceptions.

In enumerating some of the chief processes affecting the rocks a number of familiar terms do not appear. Among these

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]		[illegible]	[illegible]
	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]		[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	Mountain ranges, great basins and seas Salients Fault scarps
[illegible] (as masses)	[illegible]	Intrusive	Dikes, veins, sills, [illegible]	[illegible]
		Effusive Explosive	Lava sheets Ash beds	Mesas, lava fields Cones, craters
	Sedimentation			
	Cementation	Compressive		
Molar (Physical, (as particles)	Disintegration	[illegible] Caloric Biotic		Regolith, talus slopes
		Eolic		Dunes, sand ridges, etc.
		Glacic		Moraines, drumlins, kames, drift-plains, basins, some lakes
	Gradation	Hydric	Stratification	Coastal plains, peneplains, flood plains, deltas, valleys, drainage systems, etc.
	Automotion	Vital Anthropic		Coral reefs, shell-banks, etc. Mounds, etc.
Molecular, or chemical. (As molecules and atoms)	Decomposition		Fissures (some)	Sinks, caverns, etc.
	Induration			Crags, reefs, water falls (some)
	Metamorphism	Paramorphic Metasomatic		
	Mineralization		Mineral veins (some)	
	Precipitation			

may be mentioned, for examples, weathering, erosion, deformation, transportation, and deposition. These are names that, as technical terms, do not now mean very much. While they are commonly used, and perform useful functions in certain cases, they really indicate an imperfect state of knowledge of the subject, or rather remissness in careful discrimination. All are compound processes, and involve the simultaneous action of several distinct agencies. Weathering includes, among other changes, the mechanical breaking down of rock-masses through the effects of heat and cold, the action of life or the application of pressure (disintegration); it involves the chemical alteration of some of the essential constituents, by which the identity of the rock-mass is lost (decomposition); and it also embraces, in its earlier stages, chemical change in which traces of the identity of the original rock are retained, but in which there has been some metasomatic replacement.

In the same way most of the other terms applied to "processes" are found to be ill-defined. Even metamorphism, which is, in the present connection, used in its limited petrographic sense, is a loose title. Usually it carries with it the idea of rock induration. Its complexity is hinted at by the use of such compounds as "contact" metamorphism and "regional" metamorphism. It actually embraces both metasomatic and paramorphic alteration, and sometimes also mineralization and cementation. Certain diastatic and vulcanic influences also profoundly affect its exact expression.

To one trained in some other than geological science, the most striking feature of the latter is a certain vagueness that seems to pervade the entire field. This is also the main difficulty that every beginner has to overcome. While after a time this trouble ceases to impress itself on the geologist himself it is nevertheless glaringly apparent in his conversation and especially in his writings. The outcome of closer attention to the only natural scheme of classification, the genetic one, is clearer discrimination of facts, greater precision of statement, and vastly better comprehension of the whole subject.

CHARLES R. KEYES.

STUDIES FOR STUDENTS.

THE DEVELOPMENT AND GEOLOGICAL RELATIONS OF THE VERTEBRATES.

IV. AVES.

THAT the birds were derived from the reptiles there is little doubt, the structure of the limbs, head, the thoracic and pelvic girdles and the feet all show a close resemblance to that of the same regions in the reptiles. Especially is this true in the more primitive birds. The general characters that are used to distinguish the class *Aves* are the development of the anterior limbs as flying organs and the accompanying atrophy of the digits of the front foot; the fusion of the bones of the skull to form a solid brain case; the fusion of the bones of the pelvis to form a solid mass of bone; the fusion of more or fewer of the dorsal vertebræ and the development of feathers. To these characters there might be added for all recent birds the absence of teeth. In the most primitive bird that we know there is not one of these characters developed in anything like a complete state, except the presence of feathers. In fact, if it were not for the fortunate accident of the preservation of the fossil in the fine grained beds of the Lithographic slates of Solenhofen, so that a cast of the feathers has been preserved, there would be some difficulty in deciding the true nature of the animal. The bones of the head and the pelvis are not coössified; the digits of the anterior limb are developed with functional claws; the vertebræ are distinct and there are many teeth in each jaw.

The Dinosaurs have been regarded as the direct ancestors of the birds, both *Compsognathus* and *Ornithomimus* of the Theropodous division having been considered as the forms from which they were derived, however there is not sufficient proof to

warrant our acceptance of either of these forms. Haeckel in his work on the phylogeny of the vertebrates thinks that the ancestor of the birds must be sought among the most primitive of the Dinosaurs of the Triassic or even earlier, among the *Rhyncocephalia* and the *Proganosauria*. Smith Woodward in his very recent work on Vertebrate Palæontology is content to say, "The earliest known birds exhibit a distinct approach to the *Reptilia* in several characters, but do not afford any indication as to the particular group from which they evolved. The general opinion is, that they are more closely related to certain *Dinosauria* than to any other forms hitherto discovered."

Following the classification adopted by Smith Woodward and in Parker and Haswell's Zoölogy, the class *Aves* may be divided into two subclasses, *Archæornithes* and *Neornithes;* the same groups were called by Haeckel, *Saururae* and *Ornithurae*. The first subclass is characterized by the features mentioned above. There is but one genus known and this is represented by but three specimens, two nearly perfect skeletons and a single impression of a feather.

Archæopteryx from the Lithographic Beds of the Upper Jurassic of Bavaria. Besides the characters mentioned above the animal was distinguished by the possession of a very long bony tail with a pair of feathers growing from each vertebra. The body of the animal was well covered with feathers and the remiges of the wings were well developed. It was about the size of the ordinary crow.

The *Neornithes* are divided into two groups, the *Ratitæ* and the *Carinatæ;* the flightless and the flying birds. The first group is of rather variable limits, some authors including in it all the birds without wings or with poorly developed wings without a keel upon the sternum, and without considering the origin of the condition, whether it is original, persistent from very early forms, or whether it is the result of degeneration from lack of use. Thus Smith Woodward includes among the *Ratitæ* certain forms that are considered by other authors degenerate *Carinatæ*.

The divisions *Ratitæ* and *Carinatæ* are assigned different values by the various writers on the subject, some considering them as orders and the other groups of the birds suborders, while others regard them as divisions of their class and all the other groups as orders. Probably the latter has the greatest following among zoölogists. It will be possible here to consider only those groups that are of importance in geological history.

Æpyornithes: extinct, gigantic birds represented by fossils from the post-Pleistocene of the island of Madagascar. They resembled the living *Apteryx* of New Zealand. *Æpyornis* is the most typical genus. It was of great size, the long bone of the leg, tibio-tarsus, was about two feet and a half long. In general form the members of this and the succeeding order resembled the modern ostriches.

Immanes.—The "Moas" or *Dinornithidæ*, were gigantic forms that existed as late as historical time, they were hunted by the natives of the island of New Zealand, where they were developed. They are not known from formations earlier than the Pleistocene, with the possible exception of a few fragments from what may be the Pliocene. They closely resemble the living *Apteryx*, and are sometimes grouped with it and the Emus and Cassowaries in an order *Megistanes.*

Dinornis is the best known of the genera; the scapular arch was almost entirely atrophied and the sternum was entirely without a keel; the hind legs were very stout and strong; the largest known species stood a little over ten feet high.

Pachyornis was remarkable for the massive nature of the hind limbs; as a whole the animal was smaller than the *Dinornis.*

Most of the existing Ratite birds are known from the superficial deposits of the countries where they are now found; an extinct Emu is known from the eastern part of Australia; remains of Rheas are found in South America and the Ostriches are represented by remains from the Siwalik Hills of India and from the Island of Samos in the Mediterranean.

Carinatæ.—Next to the *Archæopteryx*, probably the most interesting group of birds that is known are the peculiar toothed

forms from the Niobrara Cretaceous of Kansas. These were described by Marsh and called by him the *Odontornithes*, he distinguished two orders, the *Odontolcæ* and the *Odontormæ* (*Icthyornithes*).

Odontolcæ: large, flightless, swimming and diving birds that resemble the modern diving birds, Loons, etc., in many respects, and the Ratite birds in others. The front limbs are almost entirely atrophied, the humerus being represented by a slender stylet of bone; the skull was elongate and the jaws were furnished with many sharp teeth that were set in a common groove for each jaw.

Hesperornis, the most typical genus, was a large form about three feet high. A similar form *Enalornis* is indicated by remains from the Greensand of Cambridge, in England, but the structure of the anterior limbs is as yet unknown.

Odontormæ (*Icthyornithes*): much smaller birds than the former with well developed wings; the jaws were long, as in the preceding genus and were provided with teeth that were set in individual sockets; the vertebræ were peculiar in that the faces, both anterior and posterior, were deeply concave. The bird was much like the modern Tern in external characters.

Icthyornis is the only well-known genus from the Niobrara Cretaceous of Kansas.

The modern birds have many representatives among the fossil forms of the late Tertiary, among the most interesting of these are:

Gastornis, a large flightless bird from the lower Eocene of the western part of Europe. It was peculiar in that the bones of the skull remained separate instead of forming the usual solid brain case.

Apatornis, *Diaphaptoryx*, and *Aphanapteryx* from New Zealand, the Chatham Islands, and Mauritius respectively were gigantic rails that greatly resembled certain of the living rails.

Phororachos was an enormous raptorial bird whose remains are found in the Tertiary of Patagonia.

The Dodo (*Didus*) and the Solitaire from the islands of

Mauritius and Rodriguez were large ground pigeons that had lost, to a great extent, the use of the wings; they were found living by the first travelers that visited the islands, but were speedily exterminated.

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V. MAMMALIA.

The earliest known remains of the mammals are from the Triassic rocks of England and America. Between these earliest of the mammals and their direct reptilian ancestors there is but a very little gap, even in the imperfect record afforded by palæontology. Every step in the transition from the reptilian structure to the mammalian can be traced in the fossil forms, except the final disappearance of a separate bone in the skull, the quadrate, which supports the lower jaw, and the coalescence of the many bones of the lower jaw to form the single mandibular bone of the mammals.

Recalling the structure of the Theriodont and the Gomphodont reptiles of the Permian time we have no need to be surprised at the early appearance of the mammals in time. Speaking of the origin of the mammals, Osborne has said: "Two of the types of the Theromorphs of the Permian and Lower Triassic, namely, the *Theriodontia* and *Gomphodontia*, supply many of the characters which we have expected to find in the ancestry of the Mammals. In fact, they embrace the few osteological characters placed in Haeckel's Promammalia, or Huxley's Hypotheria, as well as the more numerous characters which we have

subsequently put, into the mammal archetype. The *Theriodontia* resemble in their dentition and structure the minute *Protodonta* described by Osborne from the Triassic, but differ in the compound character of the jaw bones, as well as in their surpassing size. In tooth structure they are also prototypes of the *Triconodonta* or Marsupials of the Jurassic period. On the other hand, the herbivorous *Gomphodontia*, including *Tritylodon*, are prototypes of the great phylum of Multituberculata, which, in turn, upon extremely slender evidence, however, have been associated with the Monotremata."

So close is the resemblance between the reptiles and the mammals at this point that one of the *Gomphodontia*, the Tritylodon mentioned by Osborne, was originally described from the skull as a mammal by Owen. The Mammalia are generally divided into three subclasses, the *Prototheria*, *Metatheria*, and *Eutheria*.

PROTOTHERIA a small group comprising among the living forms only the peculiar Monotremes, the Duckbill (*Ornithorhynchus*), and the Spiny Anteater (*Echidna*) of Australia. The animals are characterized by the possession of a distinctly reptilian type of shoulder girdle, with distinct interclavicle and coracoid bones; by the presence of a single external opening for the excretory and genital organs and by their oviparous method of reproduction. The Duckbill has an edentulous horny covering to the jaws in the adult stage that has given it its name, but in the very young there are two or more broad flat teeth in each jaw that recall very strongly the teeth of the *Gomphodontia*. There are no fossil remains of these forms known earlier than the Pleistocene. The bones of a large species of the Echidna have been found in deposits of that age in Australia.

The number of forms of the fossil mammals is so great that it will be impossible to discuss many individual genera, as was done with the preceding groups, and in all except especially important cases the descriptions must be limited to the families or even larger divisions.

METATHERIA, animals usually called *Marsupalia;* possessed of

a pouch in which the young are borne by the mother for some time after birth; there are a pair of bones in the abdominal wall that are attached to the anterior end of the pubis on each side and support the pouch; the shoulder girdle is of the usual mammalian type.

Multituberculata, or *Allotheria*, as they are sometimes called, is a group of rather doubtful relations; they have been regarded as belonging to both the *Prototheria* and *Metatheria*, but probably belong with the latter; they are known only from fragments of the skulls and from isolated teeth. The time range of the forms is rather limited, extending from the Upper Jurassic to the Upper Cretaceous. There are three families known: the *Bolodontidæ*, *Plagiaulacidæ*, and the *Polymastodontidæ*.[1]

Bolodontidæ: forms in which the premolars are somewhat molariform and the upper ones have four tubercles. The molars of the upper series have two rows of tubercles. There were strong incisor teeth. *Bolodon*, from the Purbeck layers of Dorsetshire; *Allodon*, from the Upper Jurassic of Wyoming; *Chirox*, from the lowest Eocene, Puerco, of New Mexico.

Plagiaulacidæ: known mostly from the teeth of the lower jaw. The incisors large and rodent-like, the premolars different from the molars, compressed laterally, the posterior one much larger than the rest, and having the side corrugated by deep grooves that extend diagonally in an antero-posterior direction, making the tooth a most efficient grinding organ. The molars low and flat, the lower with two and the upper with, probably, three

[1] The student must recognize that after the mammalian type of life was developed there were no changes in that group of a magnitude comparable with those which produced the various groups of the reptiles. Until comparatively recently the changes considered have been those which centered in the development of the teeth and the limbs, and it was by the study of these changes that the morphology and the classification of the various groups has been worked out. It will thus be necessary to speak in some detail of these regions. For information on this subject the student is referred to the chapter on Kinetogenesis, chap. vi, in PROFESSOR COPE'S last book, Primary Factors of Organic Evolution, published by the Open Court Publishing Company of Chicago, 1896. The book has an especially valuable bibliography of the same subject. PROFESSOR OSBORNE has published in the American Naturalist for December 1897, an illustrated article bearing on the same subject entitled "Trituberculy: A review dedicated to the late Professor Cope.

series of tubercles. *Microlestes*, Upper Trias, Rhaetic, of Wurtemberg and England; *Plagiaulax*, Purbeck of England; *Ctenacodon*, Upper Jura of Wyoming; *Ptilodus*, Puerco Eocene, of New Mexico, under this last name Osborne includes as synonyms most of the names given by Marsh to the forms described by the latter author from the Laramie Cretaceous; *Meniscoessus*, from the Laramie Cretaceous of Wyoming, under this name are grouped as synonyms many of the remaining described forms from the same region. *Neoplagiaulax*, from the lowest Eocene of France; *Abderities*, as well as many imperfectly known forms, from the Eocene, Santa Cruz formation, of Patagonia.

Polymastodontidæ: lower jaw with a very large and strong incisor tooth greatly resembling that of the recent rodents, two large molars with two rows of tubercles and a very small premolar. This form is quite near the rest of the group, but is easily distinguished by the absence of the enlarged premolars and the much larger size of the animal.

Polymastodon, from the Puerco Eocene of New Mexico.

The study of these forms has led to the best knowledge we have of the changing conditions at the end of the Mesozoic time; thus from a comparison of the similar types in the preceding and the succeeding ages we are led to the conclusion that as far as the faunal relations go the Eocene is very much nearer to the Upper Cretaceous than is the Jurassic, and this means, possibly, a slighter change in the conditions, climatic and otherwise. Osborne says: "The Laramie mammals are surprisingly near to those of the Puerco, and in some cases almost identical with them; in other cases they are of a somewhat older type, ... the greatest gap to be filled by future discovery is between this Laramie fauna and the Jurassic. For this Laramie fauna is separated from the Puerco about as widely as the Puerco is from the Wasatch, but no more widely; whereas it is separated by a profound gap from the Jurassic fauna."

The *Marsupalia*, *Metatheria* proper, is divided into two groups, the *Polyprotodonta* and the *Diprotodonta*, according to the presence of two or more than two incisor teeth in the jaws.

Polyprotodonta: carnivorous or insectivorous forms of small size with a large number, 4–5, of incisor teeth and many molar and premolar teeth, 8–12 in opposition to 6–7 possessed by recent forms. The premolars are simpler than the molars.

The suborder is divided by Osborne into three groups, *Protodonta*, *Triconodonta*, and *Trituberculata*. The first, the *Protodonta*, is distinguished by having the premolars simple and conical in shape and the molars with a middle part slightly elevated above a posterior and an anterior accessory cone. The molar teeth are single-rooted, but there is a deep groove on each side that indicates the coming division of the root into two parts. The group is represented by two specimens only. These are from the Triassic rocks of North Carolina and consist of the lower jaws only. *Dromotherium* and *Microconodon*.

Triconodonta: forms very similar to the last, but with a smaller number of molar teeth. The middle cone of the molars is better developed and the accessory cones are separated farther from the main one and have a much greater part in the function of mastication. The roots of the teeth are entirely separated. The forms are almost entirely from the Jurassic layers of England, and Wyoming. Typical genera are:

Amphilestes, Oolite from near Oxford, England.
Phascalotherium, Oolite from near Oxford, England.
Tinodon, Upper Jurassic of Wyoming.
Priacodon, Upper Jurassic of Wyoming.
Dicrocynodon, Upper Jurassic of Wyoming.

Trituberculata: small forms with many molar teeth, the crowns of which are supplied with three tubercles arranged in the form of a triangle with apex of the triangle pointing inwards in the upper teeth and outwards in the lower; the importance of these forms is best realized when we remember that this tritubercular arrangement of the tubercles of the teeth is the primitive type from which all the remaining types of mammalian dentition have been derived. The *Amphitheridæ* and the *Amblotheridæ* are the two most primitive families of the suborder.

Amphitherium, from the Oolite of England, near Oxford.

Amblotherium, from the Purbeck of England.

Dryolestes, from the Upper Jurassic of Wyoming.

The *Myrmecobidæ*, *Peramelidæ*, *Dasyuridæ*, and *Didelphyidæ* are all families containing living forms, the last two have members from rocks as old as the earliest Eocene. It is of interest to note that while the family *Didelphyidæ*, the opossum, is at present confined to the North and South American continents it formerly ranged over the whole of Europe and England.

Diprotodonta.— This suborder is distinguished by the presence of only two incisor teeth in the upper jaw and one in the lower. The premolars are like the molars, or may be developed as long cutting organs, as in the *Allotheria*. There are several families, but only two are of interest to us here, as they are the only ones that contain fossil forms. The suborder, living forms as well as extinct, is entirely confined to the Australian region.

Thylacoleo is the single representative of the *Thylacoleonidae*; it was a large form about the size of the lion, with strong incisors and one of the premolars in each jaw greatly elongated in the antero-posterior direction, and compressed from side to side so as to form a long cutting edge; the rest of the dentition is quite weak. The posterior part of the head is very wide, but it narrowed rapidly as it approaches the anterior end.

Diprotodon and *Nototherium* are the representatives of the *Diprotodontidae*. The skull of the first was nearly three feet long, the incisor teeth were developed as gnawing teeth, with enamel on the outer side only and set in deep alveoli. The pos terior teeth lacked the cutting edges of *Thylacoleo*, and were adapted to grinding up vegetable material. The whole form had the bulk of the rhinoceros; the structure of the feet is unknown. *Nototherium* was very similar to this form, but was considerably smaller.

Eutheria: Animals in which there is no marsupium; the embryo is nourished by the development of a placenta that attaches it to the mother. This includes all the remaining forms of the mammals. Palæontologists recognize ten orders of the

Eutheria: the *Cetacea, Sirenia, Ungulata, Tillodontia* (?) *Rodentia, Carnivora, Insectivora, Chiroptera, Edentata and Primates.*

Edentata.—These are the lowest of the Eutheria in the scale of development. The group is characterized by the imperfect development of the dentition; the teeth are few in number, and the enamel is lacking from the surface in the more recent forms. That they are degenerate forms is shown by the fact that the earlier order had perfectly formed teeth; many of the steps in process of degeneration have been traced. Three suborders are recognized: *Nomarthra, Xenarthra,* and *Ganodonta.* The first of these is of little importance from a palæontological standpoint; it is composed of forms confined to the tropical parts of Asia and Africa. It is separated from the *Xenarthra* by characters of the vertebræ.

The *Xenarthra* is divided into five suborders, the *Tardigrada, Dasypoda, Gravigrada, Glyptodontia,* and *Ganodonta.* The first two are confined to the recent and the later Tertiary of South and Central America.

Gravigrada.—These forms, now extinct, were of gigantic size; the body was large and clumsy with a powerful tail that, perhaps, aided the animal in assuming the upright position; in the later forms, perhaps more than in the earlier, the animals walked with the side of the foot presented to the ground; the teeth were few and confined to the posterior part of the jaws; they were without any enamel upon the surface. The animals were in fact large ground sloths; they probably obtained their nourishment by uprooting trees and shrubs and feeding upon the leaves and smaller branches.

Megatherium was the largest of the forms, reaching a length of 18 to 20 feet, and a height of about 8 feet. The teeth placed close together at the posterior part of the jaw, exhibit cross ridges from the presence of slightly harder dentine. The animal is known from all parts of South America, and as far north as Georgia, South Carolina, and Texas.

Megalonyx.—This form is the representative of a separate family from the preceding; the most anterior of the molar teeth

stands far in front of the remainder, and has the appearance of a canine. The genus appears to be confined to the latest deposits of the Tertiary in the United States, and is found in the cave deposits of the southern states. The animal reached the size of an ox.

Mylodon, another form is distinguished from the others by the appearance of slight irregularity in the form of the teeth; instead of straight peg-like form, they are triangular, and the teeth of the lower jaws are somewhat figure eight shaped in outline. This genus was fully as large as the *Megatherium* and had even a greater geographical range, species being known from the pampas of the Argentine Republic, and from the caves of Oregon.

A very large number of forms have been described from the deposits of Patagonia and the Argentine Republic, and a smaller number from other parts of the southern continent, many being found on the west coast, to reach which place they must have either crossed the Andes, or emigrated down the west coast from far up in the United States. The geological range seems to have been from the upper Eocene or the Oligocene to the latest Pliocene.

Glyptodonta.—These were animals in which the body was covered by a strong carapace of bone that was made up of many small ossicles of different shapes, joining each other by suture. The armor was confined entirely to the dorsal surface, there being no plastron or ventral plate as in the turtles. The tail was large and covered with the same armor as the back. The skull was very short and high with a lower jaw of great vertical thickness. The teeth were elongated in the anterior-posterior direction, and the sides of the teeth were marked by deep vertical grooves that nearly divided the teeth into three parts. The vertebræ of the dorsal region were all united into a long tube, and the lumbar vertebræ were anchylosed with the sacrum, thus practically destroying any mobility of the spine. The feet were provided with broad, almost hoof-like claws. The animals sometimes reached a very large size. The whole suborder is extinct.

Glyptodon: a very large form that ranged from the southern part of South America as far north as Texas and Florida. The animal was about six feet long, and reached a height of three feet at the most elevated portion of the carapace. The dermal plates are sculptured in the form of a rosette. The tail is covered with a series of bony rings that are attached to the processes of the vertebræ within.

Panocthus: a large form that is confined to southern part of South America; very similar to the *Glyptodon.* The carapace was made up of four and five-sided pieces with a tuberculated surface instead of the rosette arrangement. The anterior part of the tail was protected by 6–7 large bony rings, but the posterior part was enclosed in a solid tube of bone that was slightly flattened; the surface of this tube was covered with small plates that in places gave room to larger ones that seem to have been the bases of some sort of protuberance, horny or bony. The form reached about the size of a rhinoceros.

A large number of these forms have been described from the late Tertiary deposits of Patagonia, and the Argentine Republic. The majority of them come from the Miocene and the Pliocene, though a considerable number are from the earliest, the Santa Cruz Tertiary.

Ganodonta.[1]—This group was founded in 1896 by Wortman, and considered by him as a suborder of the Edentata. The group is made up of a part of the order *Tillodontia,* which was originally considered as the ancestral form of the rodents. Not until the teeth of one of these forms was found in connection with the fore limb was it determined that they were Edentate in character. The fore limbs are similar in every respect to those of the *Tardigrada,* but the teeth are different in that they are not devoid of the enamel covering and in the presence of the anterior teeth, the incisors, and the canines. These forms occur in the earliest Eocene Puerco beds of New Mexico, and are undoubtedly the earliest forms of the Edentates. They are of

[1]Science, December 11, 1896, p. 865., Bull. Am. Mus. Nat. Hist., Vol. IX, p. 59. (Contains a full description of the Ganodonta and its geological relationship.)

extreme interest as indicating the origin of the group which has been for long one of the greatest problems of the palæontologist. Other than the interest attaching to the origin of the group is that of the geological possibility of the forms getting into the southern continent in the early Tertiary time. These forms undoubtedly originated in the United States. As there is no trace of them in the basal Eocene of South America. and they appear in great numbers and highly developed in the Middle Eocene, it seems certain that they must have emigrated from the northern land. There is little possibility that they could have taken the northern route and gained the land of Asia by the northern connection, and then worked into South America by the Antarctic continent; this is further borne out by the fact that there are no known remains of the group from the Old World beyond the incompletely identified specimen of one genus. It seems probable that there must have been a temporary connection between the two continents in the earliest or the Middle Eocene. That the forms found the conditions of life exceptionally favorable in the southern continent is evidenced by the extraordinary development both of species and of individuals.

Cetacea.—This order bears very much the same relation to the land mammals that the Plesiosaurs and the Icthyosaurs bore to the early land reptiles. The limbs have degenerated and become adapted as swimming organs, the bones of the proximal portions becoming shorter and losing their distinctive character, while the phalanges become much more numerous and there may even be added digits. In most of these forms also the hind limb is lost; the teeth become simpler and disappear in some forms; the whole body takes on the fish-like form that seems to be requisite for the aquatic life; the hair disappears and is represented by only a few scattering bristles. These remarks are equally applicable to the succeeding group, the *Sirenia*.

The *Cetacea* are generally divided into three groups, the *Archaeoceti*, the *Odontoceti*, and the *Mysticoceti*. The last two groups, the recent dolphins and the whales are represented in the fossil state by specimens from the Eocene, showing all the

characters of the recent forms. The first group, the *Archaeoceti*, is represented by a form that is known from all parts of the world, *Zeuglodon;* it has an elongate skull like the alligator, but still possesses the dentition of the land animals, in that it is differentiated into premolars and molars; the position of the nostrils and the extent of the nasal bones are also typical of the land forms, but the limbs are those of a water animal. As the form is the earliest known, it is regarded as the nearest to the primitive ancestor of the *Cetacea*. The carnivorous dentition has led to the conclusion that it, and consequently all of the order was derived from a carnivorous mammal. The high degree of development of the order at its earliest appearance, indicates that these animals must have begun their specialization some time in the Cretaceous before we know of any mammals that could have produced them.

The *Sirenia* have a like history to the foregoing group. They are, without doubt, the descendants of land-living forms, but are derived from ungulates, probably from the primitive *Condylarthra*, instead of from carnivorous forms. The earliest remains are from the Eocene rocks, and show that the animal was at that time still in possession of a pair of rudimentary hind limbs. Specimens are known from most of the countries of the earth, and from all deposits from the earliest Eocene up. *Rhytinia*, Steller's Sea-cow, became extinct as late as the middle of the eighteenth century. It was found in great abundance on the shores of Alaska and the neighboring islands by the early explorers, and was slaughtered for food by the whalers.

Ungulata.—This is one of the largest groups of the mammals, including all of the herbivorous forms with the exception of the rodents. They are all land-living forms, with the limbs modified as organs of locomotion and the terminal phalanges armed with broad, flat, horny coverings or hoofs. The dentition is adapted to a vegetable diet or to an omnivorous one, as in the pig. The dentition is diphydont, *i. e.*, there is a milk set that is later replaced by a permanent one.

There are generally recognized eight suborders of this order:

Condylarthra.
Perissodactyla.
Artiodactyla.
Amblypoda.
Proboscidea.
Toxodontia.
Typotheria.
Hyracoidea.

The *Condylarthra* are forms with five functional digits on each foot; plantigrade in the habit of walking, and with small hoofs on each digit. The astragulus has a long neck, and the distal articular face, for the navicular, is rounded. The teeth are multitubercular and complete in number in each jaw. It was in these regions that the changes took place that have made it possible to trace out the lines of development of the ungulates, and, as Cope thought, the lines of the *Carnivora* and the *Primates* as well.

There are several families of the suborder, but it will be as well, probably, to take one of the forms from one of the families and describe it as typical of the whole group.

Phenacodus is the best known of the suborder. By great good fortune the nearly perfect skeletons of two individuals are known. The whole animal was about the size of a mastiff dog. The first and fifth toes on both the fore and the hind feet are shorter than the others, and show already the tendency to a reduction in number that is the dominant line of evolution in the foot structure of the ungulates. Another thing, the bones of the two rows of the carpus and the tarsus are arranged one above the other, instead of being alternate in position, *i. e.*, one of the upper row being opposite the space between two of the lower row. The latter arrangement is readily seen to be by far the strongest, and the development of the ungulates is marked by the gradual acquisition of this alternate arrangement of the bones in place of the serial arrangement of the *Condylarthra.* There was a long tail; the skull was low and flat, with large

orbits that are open behind; the multitubercular teeth indicate that the animal was omnivorous in its diet; the brain was small and smooth, devoid of deep convolutions such as exist in most of the mammalian brains.

Periptychus was a very similar form from the same horizon as Phenacodus.

Pleuraspidotherium and *Orthaspidotherium* are forms from the lowest Eocene, Cernays, of France; they are similar in the essential features to the American *Condylarthra*, and show that the group was widespread in its geographical range, as might be expected from its generalized characters.

Starting from the *Condylarthra*, with its generalized dentition and five-toed feet, there were developed two lines of the *Ungulata*, which include all of the living and extinct forms. In one line the weight of the body is borne on the three middle digits of the feet, or, in the more advanced forms, on the middle one of all the digits. These forms were called by Owen, in 1849, the *Perissodactyla*. They are generally referred to as the "odd-toed" animals, with the idea that there is always an uneven number of toes on the feet, but this is erroneous, as some members of the group have four toes on the feet; the essential thing is that only three of them take any part in supporting the body, the other being a rudiment from the original pentadactyl arrangement. The next group of the *Ungulata* is the *Artiodactyla*, the forms with an even number of toes supporting the body. There are, of course, many points in the structure of the two groups that are correlated with the development of the toes; thus, in the first group there are never any horns developed on the parietal bones, and the horns are never paired, but there are horns developed on the median line on the nasal bones, as in the rhinoceros. There is no living form of the *Perissodactyla* that ruminates; there is a characteristic number of dorsal vertebræ for each group; the astragalus of the two groups has a very different form, and there is always a third trochanter on the femur of the odd-toed forms.

Osborne, in Part I of his memoir on the Extinct Rhinoce-

roses, has given perhaps the best summary of the position of these forms. He says: "The Perissodactyla may be primarily divided by the fundamental pattern of their upper grinding teeth into four superfamilies, as follows:

1. TITANOTHEROIDAE: including the single family (1) *Titanotheridæ.*

2. HIPPOIDEA: including the two families (2) *Equidæ* and (3) *Paleotheridæ.*

3. TAPIROIDEA: including the two families (4) *Tapiridæ* and (5) *Lophiodontidæ.*

4. RHINOCEROTOIDEA: including the three families (6) *Hyracodontidæ*, (7) *Amynodontidæ*, and (8) *Rhinocerotidæ.*

To these should be added:

5. CHALICOTHEROIDEA, an aberrant superfamily, with molar teeth related to the Titanothere pattern, and perissodactyl feet provided secondarily with claws.

The eight families, in the order named, may be imagined as the contemporary branches of the four superfamilies, these in turn having branches from a still unknown Perissodactyl stem form — probably a Cretaceous member of the Condylarthra.

These eight families, familiarly known as the Titanotheres, Horses, Paleotheres, Tapirs, Lophiodonts, Hyracodonts, Amynodonts, and Rhinoceroses, when regarded as a series, present upon the one side close resemblances, or perhaps affinities, to the Artiodactyla, and an extreme departure from the Artiodactyla on the other. Thus the Titanothers exhibit many resemblances to the Artiodactyls, while the Rhinoceroses exhibit none at all, and are in many respects the most typical Perissodactyls.

Superfamily RHINOCEROTOIDEA, or Rhinocerotine group. The three distinct families included in this division may be popularly known as the Cursorial or Upland Rhinoceroses, the Aquatic Rhinoceroses, and the True or Lowland Rhinoceroses. They are briefly distinguished as follows:

Hyracodontidæ: cursorial rhinoceroses; *Hyrachyus* and *Hyracodon;* manus functionally tridactyl; upper and lower incisors and canines persistent and uniformly developed.

Amynodontidæ: Aquatic Rhinoceroses; *Amynodon* and *Cadurcotherium;* manus functionally tetradactyl; incisors atrophied; upper and lower canines greatly enlarged.

Rhinocerotidae: True Rhinoceroses; *Aceratherium* and *Rhinoceros;* manus functionally tridactyl; upper canines atrophied; median upper incisors and lower canines opposed and irregularly developed.

Our knowledge of the three divisions of this superfamily extends back only to the Middle Eocene of America and Europe, namely, to the Bridger and the somewhat older Egerkingen Beds of Switzerland. No Rhinoceroses of any kind have as yet been found contemporary with the primitive Horses and Tapirs of the Wasatch of America or the Suessonian of France, but they will undoubtedly be discovered in these or older rocks either in America or Europe, with characteristics as sharply defined as those of the other perissodactyl families.

Certainly before the Middle Eocene of North America, the Rhinocerotoidea had here or in some unknown region specialized and diverged into the three above-mentioned families, which some authors place in the single family Rhinocerotidæ. While it is quite possible that in the Wasatch or Suessonian period this group consisted of a single family, in the Bridger we certainly find two distinct families, the Hyracodontidæ and Amynodontidæ, and in the White River these coexist with the Aceratheriinæ, or ancestral true Rhinoceroses. The members of each family were evidently as widely different in their external form as in their dental and skeletal structure. . . . .

There is no doubt, therefore, that as a matter of taxonomic clearness as well as of phylogenetic fact it is best to consider these three families as entirely separate and undergoing a parallel development, probably in Europe as well as in America.

Specialization in habits.—The wide separation of these three families will be fully apparent after we have examined their chief primitive, parallel, and divergent features. Parallelism is mainly confined to the evolution of the molar teeth, for in every feature of the incisor teeth, the skull, the vertebræ, and the limbs, these

families specialized and diverged rapidly. The rhinocerotine differentiation in the broad sense of the term, imitated that of the Perissodactyla as a whole in its general functional radiation. They ran either into upland cursorial types, which competed with the Horses and the Ruminants, or into the lowland marsh or river dwellers, which competed with the Tapirs and the Titanotheres.

Among the former were the smaller, more agile, light-chested types of Hyracodonts, simultating the Miocene Horses in skeletal structure and in the development of true hoofs. Among the latter were the short, heavy types of Amynodonts, with broad, spreading, padded feet; they probably acquired, like the Tapirs, a long, prehensile upper lip, or, possibly, a true proboscis was developed, in correlation with the rather abbreviated nasals. The elevated and prominent position of the orbit would bring the eye near the surface in swimming. This feature, with the long, curved tusks, undoubtedly used in uprooting, suggests the resemblance between the habits of these animals and those of the Hippopotami. The early Aceratheres were light-limbed rather swift-footed animals, intermediate in proportions between the Hyracodonts and the Amynodonts, but far less graceful and rapid than the former, yet the destiny of this family was also to finally produce both the very slow, heavy-bodied forms, such as *Aceratherium* (*Aphelops*) *fossiger*, of the Loup Fork and the stilted, long-limbed *Aceratherium malacorhinum* of the same period.

Neither the Hyracodonts nor the Amynodonts developed horns, and all the early true Rhinoceroses had weak, hornless, nasals so that they probably appeared externally more like enlarged modern Tapirs than the well-armed animals we are now familiar with.

They did not interfere with each other because each enjoyed a different local habitat, while occupying the general geographical regions. The Hyracodonts dwelt in the drier grassy plains. The Amynodonts frequented the river and lake borders. Up to the time of the extinction of these two related families, the true

Rhinoceroses maintained a somewhat uniform structure, both in Europe and America, differing, so far as we know, in size rather than in proportions. Their dentition and their feeding habits were probably similar to those of the *R. bicornis* of Africa and the *R. sondaicus* and *R. sumatrensis* of Asia, namely, upon leaves, shrubs, and softer herbage. After the extinction of the rival families, however, there was naturally a tendency on the part of the true Rhinoceroses to enter the peculiar local habitats previously occupied by the Hyracodonts and the Amynodonts, and they accordingly diverged into upland and lowland, short and long-limbed, brachydont and hypsodont types.

Geological and geographical distribution.—(1) The Hyracodontidæ, including *Hyrachyus*, *Triplopus*, and *Hyracodon*, are very abundant, displaying a great range of size in the Middle Eocene and Oligocene of North America, and are possibly represented in the Eocene of Europe by species which have been mistakenly referred by Rutimeyer and others to *Lophiodon*. (2) The Amynodontidæ are known from the Upper Eocene or Washakie and Uinta Beds of North America, and are also possibly represented by species referred to *Lophiodon* in the Eocene of Europe, although it is difficult to determine this from the teeth alone; the latest American type is *Metamynodon* of the Oligocene, but *Cadurcotherium* represents a later and probably final stage of development in the Oligocene and Lower Miocene of France. (3) The Rhinocerotidæ are first doubtfully known in the Upper Eocene of Europe, then suddenly appear in abundance in the Lower Oligocene. They are grouped in four subfamilies. (1) Aceratheriinæ of Europe and America. These hornless types ranged through all the Miocene of North America, and then apparently became extinct upon this continent, but in Europe they extended into the Pliocene, and in Asia into the Middle Pliocene. (2) The Diceratheriinæ, or pair-horned types, have been found only in the Lower and Middle Miocene of North America and Europe. (3) The earliest Rhinocerotinæ, or Rhinoceroses possessing median horns, branched off from the Aceratheres in the Middle Miocene of Europe; they divided into three sub-

series which are scattered widely over Europe, Asia, and Africa, and displayed a remarkable specialization. (4). The most aberrant family is the Elasmotheriinæ, thus far found only in the Pleistocene of Siberia."

DISTRIBUTION TABLE, AMERICAN HORIZONS.

	Lower Eocene *Wasatch*	Middle Eocene *Bridger*	Upper Eocene *Uinta*	Oligocene *White River*	Lower Miocene *John Day*	Upper Miocene *Loup Fork*
I. HYRACODONTIDÆ.						
Hyrachyinæ						
Hyrachyus..........	......	×				
Colonoceors..........	......	×				
Triplopodinæ.						
Triplopus..........	......	......	×			
Hyracodontinæ						
Hyracodon	......	......	......	×		
II. AMYNODONTIDÆ						
Amynodon..........	......	×				
Metamynodon..........	......	......	......	×		
Cadurcotherium[1]						
III. RHINOCEROTIDÆ						
Aceratheriinæ..........	......	......	......	×	×	×
Diceratheriinæ..........	......	......	......	......	×	
Rhinocerotinæ.						

The superfamily TITANOTHEROIDÆ, with the single family *Titanotheridæ* is generally divided into two subfamilies, the *Paleosyopinæ* and the *Titanotherinæ*. The group seems to have developed in the later Eocene time, and to have reached its greatest development in the Miocene near the middle of which time it disappeared. Starting with forms about the size of the Tapirs of modern time the animals gradually increased in size until at the time of their extinction they had reached elephantine proportions. In general appearance they must have been similar to the Tapirs, with a broad, heavy body, stout limbs and a long upper lip. The brain cavity was small, and the brain was probably devoid of deep convolutions. The group reached by far its greatest development in North America, but a few forms have been discovered in the Upper Eocene and the Lower Mio-

[1] Phosphorites of Quercy.

cene beds of Europe. The two subfamilies differed chiefly in the larger size and the more complex dentition and foot structure of the *Titanotherinæ*.

Paleosyops is the most characteristic member of the first subfamily. It is found in the Lower and Middle Eocene of North America (Wind River and Bridger). The dentition was complete, that is, the incisors and premolars were all present; the premolars were simpler than the molars; the skull was without horns and without the concave outline of the upper surface that is so apparent among the Titanotheres. One species was about six feet long and three feet high.

Diplacodon from the Upper Eocene of the United States, Uinta, is of great interest in that it is in many characters related to the Rhinoceroses, and at the same time stands as an almost perfect connecting link between *Paleosyops* of the Lower Eocene and the Titanothers of the Miocene.

Titanotherium was a large form confined to the Lower Miocene and reaching its greatest development in the United States; a few specimens have been found in Europe. Despite the rather short time in which the animal lived upon the earth it developed an astonishing degree of variability, with the result that it has probably received as many different names as any form known. Thirteen genera and thirty-one species have been described from what Osborne, after a careful study of the cranial characters, regards as "one or possibly two genera, and about fourteen definable species." The Titanotheres are characterized by the development of a pair of horns on the anterior portion of the snout; the gradual loss or the tendency to the loss of the incisor teeth; the complex dentition, in which the premolars are as complex as the molars and the increased size. The largest species reached a length of between twelve and fifteen feet and a height of about seven feet. Remains are known from a large number of regions in the United States and Canada, showing that the animal roved over a wide territory.

E. C. CASE.

REFERENCES FOR THE MAMMALS HERE DISCUSSED.

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COPE, E. D., Tertiary Vertebrata, Vol. III. United States Geological Survey of the Territories, 1884.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.[1]

TODD[2] maps and gives a general description of the geology of South Dakota. Archean[3] rocks are present in the Black Hills, near Sioux Falls, and near Bigstone Lake in the eastern part of the state.

In the Black Hills the Archean rocks are slates and schists, intruded by granite. The metamorphic effects in the slates and schists become more pronounced as the contact with the granite is approached. Following Van Hise, it is believed that their metamorphism was largely brought about by the intrusion of the granite. The thickness of the slates and schists is from 10,000 to 100,000 feet. In age they are believed to correspond to the Lower Huronian of the Lake Superior region. The granites, while younger than the slates and schists, are still pre Cambrian.

The Sioux quartzite is similar to the quartzite of Baraboo and the Chippewa valley, of Wisconsin, and, following Irving and Van Hise, it is believed to be of Upper Huronian age.

Near Bigstone Lake are exposures of granites, probably of Laurentian age.

All the Archean rocks are overlain unconformably by Cambrian rocks which in general dip away from the Archean exposures.

Keyes[4] gives the result of an examination of the Sioux quartzite. Impressions were seen at several points in the bedding planes of the quartzite which so much resembled those of lamellibranchs of the Cardium and Cytherea types, that, notwithstanding strong pre-conceived notions of the ancient age of the Sioux rocks, faith in their old age was very much shaken. It is concluded that the Sioux formation should be considered as pre-Cambrian until indisputable evidence to

[1] Continued from p. 753, Vol. VI, JOUR. GEOL.

[2] A preliminary report on the geology of South Dakota, by J. E. TODD. South Dakota Geol. Survey, Bull. No. 1, 1895, pp. 172. With map.

[3] Archean is used to designate the pre-Cambrian.

[4] Opinions concerning the age of the Sioux quartzite, by C. R. KEYES. Proc. Iowa Acad. Sci. for 1894, Vol. II, 1895, pp. 218–222.

the contrary is produced, but that there now exist certain doubts concerning the accuracy of this view.

Keyes,[1] in an account of the characteristics of the Ozark Mountains, briefly describes the Archean and Algonkian rocks of the region. Archean rocks occur at the east and west ends of the Ozark uplift. The best known of the areas is the eastern one, the Iron Mountain district of southeastern Missouri. Here the largest areas occur in the vicinity of the peak from which the district takes its name, and other smaller areas are scattered over a considerable range of adjacent territory. The Archean rocks in the Iron Mountain district are granites and porphyries, the latter predominating, both of which are broken through in numerous places by basic intrusives.

At the western end of the Ozark uplift, in Indian Territory, are Archean rocks, principally granites, of which there are many varieties, cut, as in southeastern Missouri, by dikes of basic material.

Immediately overlying the Archean in a number of places are beds of conglomerates and slates provisionally referred to the Algonkian. These appear to best advantage on Pilot Knob.

Haworth[2] describes and maps the pre-Cambrian geology of the area of the Iron Mountain sheet in southeastern Missouri, which covers portions of Iron, St. Francois, and Madison counties. The pre-Cambrian rocks are crystalline, massive, Archean rocks, and crystalline, stratified, Algonkian rocks.

The Archean rocks in general form the uplands. They may be divided into two general classes, basic eruptives and acid eruptives, including granites and porphyries.

The basic eruptives, of remarkably uniform character, occur principally in the southeastern part of the area, usually in dikes cutting through the granites and porphyries, but in a few cases in the form of bosses almost circular in outline. The general trend of the dikes is northeast-southwest.

The granites occur mainly in two large areas, though they are found occasionally in small patches within the porphyries. The two

[1] Characteristics of the Ozark Mountains, by C. R. KEYES. Rept. Missouri Geol. Survey, Vol. VIII, for 1894, pp. 317–352. 1895.

[2] Report on the Iron Mountain sheet — the Archean rocks, by ERASMUS HAWORTH. Rept. Missouri Geol. Survey, Vol. IX, 1896, pp. 15–27. With Sheet No. 3.

areas are the Graniteville and Stout's Creek or St. Francois areas. The porphyries occur in numerous large, uniformly distributed areas, making up nearly half the area of the entire sheet. They include what have been called by other writers quartz-porphyry, feldspar-porphyry, felsite, felsophyre, and orthophyre.

Numerous observations show gradations between the granites and porphyries, and it is concluded that the granite and porphyries were formed from the same or similar magmas, and that their difference in texture is due to crystallization under different conditions.

Algonkian rocks are found near the center of the area, capping the Archean rocks of Pilot Knob. They comprise conglomerates and slates, chiefly the former, and include the iron ore deposits of the locality. The pebbles of the conglomerate are mostly derived from the porphyry. The matrix is a fine felsitic mass mixed intimately with varying amounts of hematite. In places the ore forms almost the entire body of the rocks.

Paleozoic rocks unconformably overlie the crystallines, and dip away from the Archean hills.

Keyes and Haworth[1] describe and map the geology of the Mine Le Mot sheet, which includes portions of Ste. Genevieve, Madison, and St. Francois counties, Missouri. Archean rocks, described by Haworth, occupy about half of the area of the sheet, forming the nucleus about which later formations are exposed in concentric belts. They are granites and porphyries, cut by dikes of diabase. The acid rocks greatly predominate, the granite making up fully nine tenths of the eruptives of the area. The porphyry appears to be the surface facies of the granite, and seems to graduate downward into the latter. This is shown where erosion has been great, and has left high granite hills which are often capped by porphyry.

Cambrian rocks directly overlie the Archean rocks, with unconformable relations.

Keyes,[2] considers the granites and porphyries in the eastern part of the Ozarks. Agreeing with Haworth, he finds the granites

[1] Report on the Mine Le Mot sheet -- General geology, by C. R. KEYES; Archean geology, by C. R. KEYES and E. HAWORTH. Rept. Missouri Geol. Survey, Vol. IX, 1896, pp. 14–44. With Sheet No. 4.

[2] Geographic relations of the granites and porphyries in the eastern part of the Ozarks, by C. R. KEYES. Bull. Geol. Soc. Am., Vol. VII, 1896, pp. 363–376. Pl. 17.

and porphyries to be different facies of the same magma. Further agreeing with Haworth, he finds that the granite occupies the lower ground, the porphyries the higher ground, and that, where there are gradations between the two, the granites are at the base of the hills while the porphyries are at the top, with transition zones between. The granites occupy a comparatively small area in the northeastern part of the district. This is an area of low elevation and near the Mississippi River, and distribution is explained as due to differential erosion. The physiography of the district is discussed, and the conclusion is reached that the crystalline rocks have undergone very considerable erosion since Cambrian time. Agreeing with Van Hise, it is held as probable that the granites and porphyries are of Algonkian age. A deep boring near Kansas City at a depth of 2500 feet penetrated black foliated mica-schist, which has the characteristics of the Archean rocks.

Keyes,[1] in connection with a description of the clay deposits of Missouri by Wheeler, briefly discusses their geological occurrence. Most of the ore-bearing conglomerates of Pilot Knob and vicinity, heretofore called Algonkian, are believed to be Cambrian. The granites and quartz-porphyries of the region are not really of Archean age, as generally considered, but are probably Algonkian. In chemical, mineralogical, and structural characters, and in absence of dynamic effects, they differ from the gneissic and schistose rocks which have been reached in deep drill holes, and, therefore, they are believed to be younger than such gneissic and schistose rocks (which, it may be inferred, are believed to represent the Archean).

The geological conditions of the crystalline rocks are unfavorable to clay deposits.

Comment.— No reasons are given for the belief that the ore-bearing conglomerates of Pilot Knob are Cambrian rather than Algonkian. Until adequate reasons are presented, the conclusion of Haworth, Van Hise, and other workers in the field, that the rocks are Algonkian, must be presumed to be correct.

McConnell[2] reports on an exploration of the Finlay and Omenica

[1] Clay deposits, by H. A. WHEELER — Chapter on the geological occurrence of clays, by C. R. KEYES. Missouri Geol. Survey, Vol. XI, 1896, pp. 36–37.

[2] Report on an exploration of the Finlay and Omenica rivers, by R. G. MCCONNELL. Ann. Rept. Geol. Surv. of Canada, for 1894, Vol. VII, Part C, 1896, pp. 40.

rivers in the Rocky Mountains of western Canada. The Archean[1] rocks of the district consist of a series of well foliated mica-gneisses, mica-schists, hornblende- and actinolite-schists, quartzose schists, and crystalline limestones. The rocks of the series are usually evenly bedded, and conform in dip to the overlying formations. To the series the local term Shuswap is applied.

Shuswap rocks are found on both sides of the Finlay River, from its mouth up to its junction with the Ingenica. North of this point the formation divides. The eastern limb follows the eastern slope of the Finlay valley northwestward to the Quadacha and for some distance beyond. It has a width of four miles at Paul's Branch, where it forms the most westerly range of the Rocky Mountains. This width decreases towards the north and increases to the south. The western limb bends away from the Finlay above the Ingenica, but crosses it again at the great bend which the Finlay describes after leaving the Rocky Mountains, and continues on to the north. The width of this band was not ascertained, as its western boundary was not reached.

Another area of Shuswap rocks, separated from the first by a band of limestones, occurs on the Omenica River above the Oslinca. The band has a width of ten miles.

The Shuswap series is overlain by Lower Paleozoic strata.

Peale[2] maps and describes the geology of the Three Forks quadrangle of Montana. Archean gneisses and Algonkian sediments occupy large areas. The Archean gneisses occur principally in the foothills of the Bridger range, the mountain masses at the northern and southern ends of the Madison range, west of the Madison valley and north of Virginia City, the southern part of the Jefferson range, the foothills of the Gallatin range, south of the Gallatin valley, and beneath the Bozeman Lake beds at the southern end of the plateau, between the Gallatin and Madison valleys. The rocks referred to the Archean may possibly include some that eventually may be referred to the Algonkian. The contacts of the Archean with the overlying sedimentaries are, in all cases, unconformable.

The Algonkian series comprises two divisions, the Cherry Creek beds, and the Belt formation.

[1] In conformity with the usage of Canadian geologists, Archean is above used in the sense of pre-Cambrian.

[2] Geol. Atlas of the United States, Three Forks Folio, No. 24, by A. C. PEALE. Washington, 1896.

The Cherry Creek beds occupy an area of thirty to forty square miles in the foothills immediately west of the Madison River and a few miles north of the southern boundary of the quadrangle, and also a small area on the east side of the Madison valley, at the western edge of the Madison range. The rocks are marbles and interlaminated mica-schists, quartzites, and gneisses. Between Cherry Creek and Wigwam Creek, on the west side of the Madison valley, Cambrian strata rest unconformably upon the upturned edges of the Cherry Creek beds. Before the deposition of the Belt formation, the Cherry Creek beds suffered extensive deformation.

The Belt formation occurs in the northern portion of the district —in the foothills of the northern portion of the Bridger range, in the hills north of the Gallatin and East Gallatin rivers, and in the rugged hills of the Jefferson canyon. In the lower portion of the formation are coarse sandstones and conglomerates, in the central part appear argillites and siliceous limestones, and in the upper part sand stones predominate. The Belt formation is overlain by the Flathead (Cambrian) quartzite. It is possible that further investigation may result in the reference of this formation to the lower part of the Cambrian. At present, however, it is referred provisionally to the Algonkian.

The Flathead and Gallatin formations (Cambrian) rest with marked unconformity upon the Archean for three fourths of the district; for the remainder of the district they rest upon the Algonkian, and the unconformity, if it exists, is very slight.

Weed and Pirsson map[1] and describe the geology of the Castle Mountain mining district of Montana. The Belt group of rocks, assigned to the Algonkian, occupies large areas in the district. The series presents no definite lithological horizons, but there is a general sequence, from the base upward, as follows:

Alternating shales and sandy beds.
Dark gray, laminated, thinly-bedded limestone.
Pearl-gray sericitic shales.
Sandy shales, with thin beds of ripple-marked sandstone.
Red shales and slates.

The series has thus far yielded no fossils. It attains a thickness of 8000 feet. Basic and acid intrusive rocks penetrate the Belt formation very freely.

[1] Geology of the Castle Mountain mining district, Montana, by W. H. WEED and L. V. PIRSSON. Bull. U. S. Geol. Survey, No. 139, 1896, pp. 165. With geol. map.

At many localities the Belt series is seen to be in conformable relations to overlying fossiliferous rocks of Cambrian age, the Flathead and Gallatin formations, and, while assigned to the Algonkian, the series is spoken of as forming the lower part of the Paleozoic of the area.

Comment.— It is unfortunate that rocks assigned to the Algonkian should be spoken of as forming the lower part of the Paleozoic, even though the Belt series may be a downward conformable extension of the Paleozoic. If properly Algonkian, *i. e.*, sedimentaries and equivalent igneous rocks below the Olenellus horizon, whether conformable or not, if referred to any era, they should be referred to the Proterozoic.

Weed and Pirsson[1] briefly describe the geology of the Little Rocky Mountains of central Montana. The core of the mountains is formed of crystalline schists, of which the type most usually seen is a black glistening amphibole-schist, or amphibolite. In the saddle west of Shellrock Mountain, the series consists of amphibole-schists and mica-schists, pink gneiss, and white quartzites, the various rocks occurring in rapidly alternating beds but a few feet thick.

The crystalline schists are overlain by Cambrian sedimentaries. Intruded between the schists and sedimentaries is a great laccolithic body of granite-porphyry.

The presence of the quartzite is taken as indicating the Algonkian age of the crystalline series. However, similar schists occurring in Montana have been generally classed as Archean, and these rocks are metamorphosed and quite unlike the slightly altered Belt Mountain Algonkian series. The crystallines are, therefore, not definitely assigned to either the Archean or Algonkian.

Hague, Weed, and Iddings[2] map and describe the geology of the Yellowstone National Park, Wyoming. Archean rocks are found near the borders of the district in the mountain ranges which encircle the Park plateau. They comprise granites, gneisses, and schists. The granites and gneisses are for the most part coarsely crystalline, and the entire series shows the effect of metamorphism by pressure.

Algonkian rocks are recognized only in the southern end of the

[1] The geology of the Little Rocky Mountains, by W. H. WEED and L. V. PIRSSON. JOUR. GEOL., Vol. IV, 1896, pp. 399–428.

[2] Geol. Atlas of the United States, Yellowstone National Park Folio, No. 30, by ARNOLD HAGUE, W. H. WEED, and J. P. IDDINGS. Washington, 1896.

Park, and are best exposed on the southern slope of Mount Sheridan, from which the formation has been called the Sheridan quartzite. The Sheridan quartzite formation comprises sandstones and slates, which contain no fossils. Unconformably overlying the Sheridan quartzite is the Ellis (Juratrias) limestone. The assignment of the formation to the Algonkian is based largely on the fact that similar rocks are unknown in the Paleozoic series, and on the fact that no sedimentary rocks older than these quartzites are exposed in this district.

Hague,[1] in a discussion of the age of the igneous rocks of the Yellowstone National Park, méntions the occurrence of rocks of Archean age in the surrounding mountain ranges. The Tetons, bordering the park to the south, consist mainly of an Archean mass, which towers high above all later rock formations. In the Absaroka range, stretching along the entire east side of the park, and formed mainly of igneous rocks, granite and schists are exposed at the northern end. The Snowy range, which shuts in the park to the north, is largely made up of Archean schists, gneisses, and granites, associated with the more recent outbursts of lava. In the Gallatin range, on the west, a body of crumpled gneisses and schists forms the nucleus of the mass. The Archean masses formed either a part of a broad continental mass, or a group of closely related islands. Resting unconformably upon the Archean are great thicknesses of Paleozoic and Mesozoic rocks.

Eldridge[2] gives an account of a geological reconnaissance across Idaho, on a northeast line through Boisé and Salmon City. Rocks are found which are provisionally referred to the Archean and Algonkian. To the Archean are referred granite and gneiss, which have their greatest development in the mountains of the western part of the state, but which are also widely exposed elsewhere. In places in the granite and gneiss are included bands of calcareo-micaceous or quartzitic slates, and in these cases the reference of the rocks to the Archean, instead of the Algonkian, is questionable. To the Algonkian is provisionally assigned the great series of micaceous, quartzitic, and chloritic schists of eastern Idaho. The reference is based merely upon

[1] The age of the igneous rocks of the Yellowstone National Park, by ARNOLD HAGUE. Am. Jour. Sci., 4th ser., Vol. I, pp. 445–457, 1896.

[2] A geological reconnaissance across Idaho, by GEORGE H. ELDRIDGE. Sixteenth Ann. Rept. U. S. Geol. Surv., Part II, 1895, pp. 217–276.

lithological character, and the resemblance to other beds in the Cordilleras which have already been so assigned. The Algonkian series in areas of strong development has a probable thickness of 3000 to 4000 feet. It is believed to be unconformable with the underlying granite.

Cross[1] describes the geology of the Cripple Creek district of Colorado. The account of the general geology is substantially the same as that previously given by Cross for the Pike's Peak quadrangle,[2] of which the Cripple Creek district is a part. Granites and gneisses occupy a large area in the district. Included in these granites and gneisses are large and small fragments of quartzite, quartz-fibrolite-schist, quartz-mica-schist, and other similar rocks. It is believed that the quartzite fragments belong to a great series of pre-Cambrian (Algonkian) sediments. Hence the granites including such fragments are not Archean; but they are older than the only Cambrian rocks as yet identified in Colorado, and they are therefore mapped as Algonkian. The schists are probably also sedimentary, but it is quite possible that some, if not all, have been produced from Archean gneisses forming the foundation upon which the Algonkian sediments were laid down.

Emmons, Cross, and Eldridge[3] describe and map the geology of the Denver basin in Colorado. Pre-Cambrian rocks form the mass of the Colorado or Front Range along the western border of the Denver Basin, later formations resting against the flanks of the mountains. In the lower canyons of South Boulder and Coal creeks, are beds of highly altered quartzite and conglomerate, associated with schists, aggregating a thickness of 1000 feet, which occupy a position between Triassic sandstones and the gneisses of the interior of the range. These are undoubtedly sedimentary and are probably of Algonkian age. In passing from these sedimentaries westward toward the center of the range there appear successively gneisses, granite-gneisses, and massive granite. As the areas occupied by the granites and sedimentaries have not been definitely delimited, and as the sedimentaries

[1] General geology of the Cripple Creek district, Col., by WHITMAN CROSS. Sixteenth Ann. Rept. U. S. Geol. Surv., Part II, 1895, pp. 13–109.

[2] Reviewed in this JOURNAL, Vol. IV, 1896, p. 371.

[3] Geology of the Denver Basin in Colorado, by S. F. EMMONS, WHITMAN CROSS, and G. H. ELDRIDGE. Mon. U. S. Geol. Surv., No. XXVII, 1896, pp. 556. With maps.

occupy but a small proportion of the pre-Cambrian area, the sedimentaries are not mapped as Algonkian, but, with the granites, are mapped as pre-Cambrian.

Osann[1] gives the geology and petrography of the Apache (Davis) mountains of western Texas. The oldest rocks found therein are the crystalline schists, which composed the greater part of Carrizo and Van Horn mountains. Here is found a great set of coarsely crystalline gneiss, mica-schist, and associated schistose rocks. These have in general a parallel northwest-southeast strike, which agrees with the axis of the range. Following Professor von Streeruwitz, these are placed with the fundamental rocks.

Sapper[2] describes the geology of Chiapas, Tabasco, and the Peninsula of Yucatan, and mentions the occurrence of Azoic rocks in the Sierra Madre Mountains. These rocks include gneiss, mica-slates, and phyllites. A band in the first northern range of the Sierra, near the plantations of Piedad and San Vincente, trends N. 7° W., and dips 5° to the N.E. Among the bowlders washed down by the Aguacate River may be seen gneiss, mica-slates, and phyllites, which indicate the presence of the crystalline formations also in the interior of the Sierra Madre.

Comment.—The term Azoic is used in a very indefinite way. It apparently is applied to all ancient crystallines, both sedimentary and igneous, and is not necessarily confined to the pre-Cambrian. However, the term is placed as a subheading under sedimentary formations, indicating, possibly, that ancient sedimentaries only are included.

Ells[3] reports on the geology of a portion of the Province of Quebec comprised in the southwest sheet of the eastern townships map (Montreal sheet), and describes pre-Cambrian rocks occurring to the east of the St. Lawrence River. These occur along the axis of the Sutton

[1] Beiträge zur Geologie und Petrographie der Apache (Davis) Mts., West-Texas, by A. OSANN. Min. und Pet. Mitt., Bd. XV, Heft 5, 6, 1896, pp. 394–456, mit Tafeln XI–XII, Fig. im Texte.

[2] Geology of Chiapas, Tabasco, and the Peninsula of Yucatan, by C. SAPPER. JOUR. GEOL., Vol. IV, pp. 938–947, 1896.

[3] Report on a portion of the Province of Quebec, comprised in the southwest sheet of the "Eastern Townships" map (Montreal sheet), by R. W. ELLS. Ann. Rept. Geol. Surv. of Canada, for 1894, Vol. VII, Part J, 1896, pp. 1–92.

Mountain range, and in the anticline east of Memphremagog Lake near Fitch Bay.

The crystalline schists of the Sutton Mountain range may be divided into two principal portions, viz., the gneissic, micaceous, quartzose, and talcose schists of the central portion or that in which the axis of the anticline is situated, and a series of green, chloritic, schistose rocks, with the characters of altered dioritic rocks, constituting an easily separable portion, flanking the central area of schists to the west, and extending from the Vermont boundary to the St. Francis in the vicinity of Richmond. This second or chloritic division is recognized also at various points on the eastern slope of the range, but it does not there present so marked a development. The age of the green schistose, dioritic portion is doubtful, but it appears to coincide to some extent with the Volcanic Group of Selwyn,[1] which he supposed to be probably Lower Cambrian or Huronian.

East of Memphremagog Lake, near Fitch Bay, the pre-Cambrian rocks are schistose, altered, dioritic rocks, occasionally with micaceous bands, and often containing clear grains of quartz. These rocks are apparently allied to the green chloritic schists of the west slope of the Sutton Mountain range, and are placed on the map as doubtfully Huronian.

Cutting the pre-Cambrian rocks, and possibly also later sediments, are a considerable variety of rocks, such as granites, syenites, diorites, diabases, serpentines, traps, etc., evidently of different ages. It is probable that the age of the granites is not far from the close of the Silurian period.

Adams[2] describes and maps the Laurentian area north of the St. Lawrence River, in the northwest corner of the southwest sheet of the "Eastern Township" map (Montreal sheet). This Laurentian area is a portion of the southern margin of the great northern Canadian area of Laurentian rocks. The area is about equally divided between the rocks of the Laurentian system and intrusions of anorthosite which break through them. The Laurentian[3] consists of red and gray ortho-

[1] Stratigraphy of the Quebec Group and the older crystalline rocks of Canada, by A. R. C. SELWYN. Rept. Geol. Surv. of Can., for 1877–8, Part A, p. 3.

[2] Laurentian area in the northwest corner of the Montreal sheet, by F. D. ADAMS. Supplementary chapter to Ell's report on a portion of the Province of Quebec. Ann. Rept. Geol. Surv. of Canada for 1894, Vol. VII, Part J, 1896, pp. 93–112.

[3] The term Laurentian is thus used as it was by Logan.

clase gneisses, presenting great variations both in structure and composition, with which are associated crystalline limestones, quartzites, and amphibolites. In certain parts of the area two divisions can be recognized in the Laurentian: an upper series, characterized by the presence of crystalline limestones, quartzites, and gneisses of sedimentary origin with a banded structure, called the Grenville series; and a lower series of gneisses in which no limestone, etc., occur, and which possess a foliated rather than a banded structure, known as the Fundamental Gneiss. Grenville rocks are recognized south of Rawdon and in the westerly portion of the St. Sauveur district. The Fundamental Gneiss apparently occupies much of the St. Jerome district. However, it has been found impossible to separate the two series and delimit them on the map.

The composition of most, if not all, of the gneisses belonging to the Fundamental Gneiss can be paralleled among the igneous rocks, and it is concluded that many of these gneisses, at least, were of igneous, probably of intrusive, origin. In the Grenville also some of the gneisses are of igneous origin. However, many are believed to be of sedimentary origin, for the following reasons: (1) they are associated with numerous and heavy beds of limestones and quartzite; (2) they have a prevailing banded character, accompanied by a very extensive recrystallization; (3) graphite is of frequent occurrence in them; (4) chemical analyses show that they have the composition, not of igneous rocks, but of sedimentary sands and muds.

The quartzite is sometimes pure, but frequently holds garnet, sillimanite, or other minerals. The limestones are coarsely crystalline marbles, sometimes pure, but at other times including grains of quartz, pyroxene, phlogopite, graphite, and other minerals.

The anorthosite belongs to the gabbros, but is characterized by the great preponderance of plagioclase feldspar, which is often so abundant as to make up the entire rock. At its contact with the gneisses are many contact phases. The anorthosite has been squeezed and foliated, together with the gneisses which it cuts, and it is concluded that its intrusion antedated at least the termination of the great earth movements which affected the Laurentian in pre-Potsdam times. In proportion as the anorthosites exhibit granulation they become light colored, some of the most metamorphosed ones resembling marble in appearance, although chemically they do not differ from the less modified anorthosites.

On the upturned edges of the Archean rocks, both gneiss and anorthosite, the Potsdam sandstone and other Cambro-Silurian rocks repose in flat and undisturbed beds.

Ells and Barlow[1] describe the physical features and geology of the proposed Ottawa Canal between the St. Lawrence River and Lake Huron. The proposed canal for several hundred miles traverses for the most part Archean rocks nearly at right angles to the strike of their schistosity or banding. The work of Logan, Murray, Lawson, and Adams, and others of the important workers on the Canadian crystalline is briefly summarized.

The Grenville series of the Original Laurentian area probably illustrates the most perfect section of Laurentian rocks which we can yet recognize. This section shows various kinds of gneisses, foliated and stratified, with foliated and massive granites and syenites, pyroxenic, dioritic, hornblendic, and quartzose rocks, and quartzite and limestone. In the basal beds of the limestone and quartzite, supposed to constitute the upper member of the series, are interstratified bands of rusty quartzose gneiss, which from the available evidence is believed to form an integral part of the limestone series. This portion presents in its banded arrangement of quartzose and calcareous rocks, the usual aspect of true altered sedimentary strata. The same well banded arrangement is also visible in some of the directly underlying gneiss; but in the case of the great mass of this gneiss, the microscopic examination shows the evidence of an aqueous origin to be wanting. Some portions of the igneous rocks are undoubtedly older than the limestones, and most probably represent the lowest portions of the earth's crust known to us. Other portions are clearly established to be of more recent age than the crystalline limestone. The oldest gneisses are foliated, rather than stratified, but in their foliation they underlie the regular series of stratified hornblende and other gneisses which occur frequently between the fundamental gneiss and the crystalline limestone and quartzite series at the summit of the section. To this fundamental series may be assigned the rocks of Trembling Mountain, those forming the anticlinals north of Lachute, rocks from various places throughout the Grenville district, and large areas at

[1] The physical features and geology of the route of the proposed Ottawa Canal between the St. Lawrence River and Lake Huron, by R. W. Ells and A. E. Barlow. Proc. and Trans. Roy. Soc. of Canada, 2d ser., Vol. I, Sec. IV, 1895, pp. 163–190. With sketch map.

different places along the Upper Ottawa River section. Concerning many of the intermediate gneisses, it may be said that while in their general aspect they resemble stratified sedimentary rocks, their study under the microscope shows them to have presumably a different origin, so that it is possible that the true altered aqueous portion may be confined to the areas of crystalline limestone with their associated bands of quartzite and grayish quartzose and hornblende gneiss. The crystalline limestones are particularly developed along the Ottawa River section, from the vicinity of Deschenes Lake, west of Ottawa city, to the village of Bryson, in which section they are frequently cut by large areas of granitic and dioritic rocks. At one place, near the Chats, the limestone is overlain by a considerable breadth of Huronian-looking schists, etc., which have been described under the name of Hastings series. The limestone has its most westerly outcrop on the Ottawa in the vicinity of Coulonge Lake, a short distance west of the Black River. From here west to the mouth of the Mattawa the limestone occurs as separate belts occupying synclinals in the upper stratified gneisses.

The rocks along the route of the Mattawa and French Rivers to Lake Huron are chiefly those which have been regarded as Laurentian gneisses. There is very little of the crystalline limestone which forms such an abundant constituent of the Laurentian farther east, and this, as well as the apparent inferior position of the gneisses, according to their banding, caused them early to be placed at the very base of the geological series, and called the Lower Laurentian series. Crystalline limestone occurs at Talon Lake, on the east shore of the Great Manitou or Newman Island in the eastern part of Lake Nipissing, as well as on two of the small islands composing this group, and on Iron Island. All the evidence seems to point to the fact that the limestone has been caught up in the gneisses during its eruption.

The foliation of the gneisses is produced either by (1) alternation of light and dark bands, or (2) by the more or less parallel distribution of the component minerals. In many of the plutonic rocks, and particularly in the granites and similar rocks, there is a marked tendency for the bisilicates to aggregate themselves in certain belts or patches (called Auscheidungen in the granites). The result of pressure on a rock characterized by the presence of these masses would be the flattening of the dark areas into more or less lenticular areas. Again, many of the dark bands are seen to have had their

origin as dikes, which have been intruded along the planes of foliation.

Smyth[1] describes pre-Cambrian diabase dikes cutting the granites and gneisses of the Admiralty Group of the Thousand Islands, St. Lawrence River. C. K. LEITH.

[1] A group of diabase dikes among the Thousand Islands, St. Lawrence River, by C. H. SMYTH. Trans. N. Y. Acad. Sci., Vol. XXIII, 1893–4, pp. 209–214.

Reviews.

The Naples Fauna (*Fauna with Manticoceras intumescens*) *in Western New York.* By John M. Clarke. 16th Ann. Rep. N. Y. State Geol., pp. 31–165, Plates I–IX.

The faunas of the Upper Devonian period in New York, are of great interest to all students of the geologic phases of palæontology. In the earliest fauna of this period, the Cuboides fauna of the Tully limestone, there appear suddenly several new types of organisms, chiefly brachiopods, among which the most important is *Hypothyris cuboides*, which have no genetic predecessors in the region. These strangers or exotic forms, therefore, must be considered as migration species whose previous evolution had taken place in some other geologic province, but which, with the establishment of some new line of communication at the beginning of Upper Devonian time, were enabled to find their way into the New York province. By a careful study of this Cuboides fauna and its geographic distribution, Professor H. S. Williams has been led to the conclusion that it first developed in the European or Eurasian province and later migrated into North America, coming in from the northwest along the Mackenzie basin, moving southward and finally eastward into the New York province.

The Naples or Intumescens fauna, which is the subject of Professor Clarke's paper, is a successor of the Cuboides fauna in western New York. Like the latter it is a widely distributed fauna in Europe, and it is always characterized by the goniatite genus *Manticoceras* of which the species *M. intumescens* is the common European form. Outside of New York the fauna characterized by this type of goniatite is found in North America only in Iowa and in the Mackenzie basin. In these two localities the characteristic goniatite is but sparsely represented, but in western New York it is present in considerable abundance and is represented by numerous species. From the evidence, therefore, it would seem that this fauna also found its way from Europe into North America by the same path along which the Cuboides fauna had migrated, but at a little later time. Along the way it left but slight

traces, but when it reached that part of the Upper Devonian seas which is now western New York, it found a wonderfully congenial environment and blossomed out anew.

The strata occupied by the normal Intumescens fauna are those of the typical Portage series of Hall in western New York. The fauna makes its first appearance, however, in the Styliola limestone in the midst of the Genesee shale, after which it disappears during the deposition of the Upper Genesee shales, to reappear in the Portage beds. Such a preliminary appearance of a new fauna, before it becomes an established normal fauna, is called by Professor Clarke a *prenuncial* fauna. The Styliola limestone, therefore, contains the prenuncial Intumescens fauna.

Further east, in the Ithaca section, the Intumescens fauna never became the normal fauna, but there existed contemporaneously with it a fauna which was constituted in large part of a recurrence of Hamilton species. Occasionally, however, a species of *Manticoceras* wandered into this region from the west and is found associated with the Ithaca fauna.

From this relation of faunas it will be readily seen that the term Portage cannot be used both in a stratigraphic and in a faunal sense. If it is used as a faunal name it must be restricted to the Intumescens fauna, the fauna of the original Portage rocks. If it is used as a stratigraphic name to include all those strata in New York which were deposited during a given portion of Upper Devonian time, it will include at least two quite distinct faunas. For the expression of the time duration and the geographic restriction of a particular faunal province, a technical term is often needed; a term which has not only a time significance, but a geographic significance as well. For this Professor Clarke has proposed the term *Zoehemera;* thus the zoehemera of *Manticoceras intumescens* would be the time during which the Intumescens fauna existed in the restricted geographic area in which it was distributed.

Professor Clarke's paper is devoted entirely to the cephalopods of the fauna, but the reader is led to believe that the remaining classes will be discussed at an early date. Of the cephalopods thirty species and varieties are recognized, twenty-one of them being described as new. Thirteen of the forms belong to the characteristic Intumescens fauna genus, *Manticoceras*. Under the older conception of species of goniatites nearly all of these might perhaps be included in the one

general species *M. intumescens*, but with the modern methods of ontogenetic study of the cephalopods, which have been used in a most satisfactory way in conducting this investigation, specific lines are drawn with far greater precision. The ontogenetic stages of most of the species are carefully described and fully illustrated by many figures in the text, so that the paper is valuable to the biologist as well as to the geologist.

STUART WELLER.

Geological Survey of Canada, Annual Report. New Series, Vol. IX, 1896. DR. G. M. DAWSON, Director.

During the year work was done in British Columbia, Alberta, Ontario, Quebec, Nova Scotia, Labrador, and the region west of Hudson Bay.

In British Columbia Messrs. McConnel and McEvoy gave their attention to the mining region around Nelson, Trail and Rossland. Some important facts are noted regarding the occurrence of ores. A boring in the Cretaceous formation at Athabasca Landing, Alberta, was carried to a depth of 1770 feet in the hope of reaching the petroleum-bearing "tar-sands" which form part of the lowest member of that formation to the northeast. The boring had to be abandoned, but other attempts will be made.

The report of Mr. J. B. Tyrrell on his work in the unexplored region west of Hudson Bay is one of special interest. He gives an historical sketch of earlier explorations of Hudson Bay and adjacent lands, many of which were connected with the search for a "Northwest Passage." The formations observed include the Recent, Pleistocene, Silurian, Cambro-Silurian, Cambrian, Huronian and Laurentian, of which the last is by far the most extensive. Pleistocene sea beaches and terraces are found at heights of 100 to 600 feet above sea level. In several places series of four to seven terraces mark shore lines of later glacial and postglacial times. The glacial geology of the region is accorded about twenty pages of the report. Several centers of glacial outflow are noted, about 140 strial directions recorded and many eskers, drumlins, moraines and extra-glacial lakes are described. A map accompanies the report.

Dr. Bell's report on his work in Ontario consists of a correlation of reports of work done at various times on the area of the French

River sheet. A new map is issued. Dr. Adams and Mr. Barlow worked on the area of central eastern Ontario covered by the Haliburton sheet. This is a region of much importance in the determination of the relationships of the various members of the Archean, and the results of Dr. Adams' investigations when completed will throw much light on the problem. Already many important facts have been brought out. An important discovery of corundum in Hastings county is announced. The work of mapping the Rainy River gold-bearing region was continued by Mr. McInnes. Dr. Ells continued the work in the area between the Ottawa and St. Lawrence rivers.

The observations on glaciation in southeastern Quebec by Mr. Chalmers show two periods of glaciation. In the first, which appears to have been local and centered in the Notre-Dame mountains, the ice moved northward to the St. Lawrence valley. The second was the Laurentian. The bowlder clays of the two differ lithologically. Marine shore lines show changes of level amounting to 600 or 700 feet in Pleistocene times. Slight postglacial dislocations of the slates were observed in many places. Dr. Bell reports on field work in the region of the Upper Ottawa and Rupert rivers and Mistassini Lake.

Mr. A. P. Low continued his exploration in northern Labrador between Hudson Bay and Ungava Bay. The rocks are principally Archean, but considerable areas of Cambrian were found. The land was completely covered by the glacial ice-sheet. The névé region seems to have been near the present watershed. On the western slope the ice moved nearly westward veering slightly to the south. On the eastern slope its initial direction was eastward but its final direction was northward to Ungava Bay. On the western slope the eskers correspond in direction with the present drainage lines, which, however do not agree with the direction of ice movement. The unstratified drift is generally in hills of irregular form and direction. The bowlders are generally of local origin. The highest marine terrace seen on the Hudson Bay side was 710 feet above sea level while the highest on the eastern slope was 620 feet above the sea.

Dr. Bailey and Mr. Fairbault worked in the gold-bearing Cambrian region of Nova Scotia, where mining is quite active.

The Chemical and Mineralogical Report by Dr. Hoffman contains the results of many analyses and assays. The report on Mineral Statistics and Mines is very complete.

R. D. GEORGE.

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